AN IRRIGATION ONTOLOGY AND ITS USE FOR LOCALIZED, ILLUSTRATION-BASED EDUCATIONAL MATERIALS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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Camilo Cornejo

I dedicate this work to my whole family and to Carolina.

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There is little doubt that economic and social development, and the benefits that accrue such as improved nutrition and health, requires an educated populace. However, illiteracy affects 860 million people as of 2005, without including a larger number of adults with low level of formal education. Most illiterates are poor, farmers, and female, living in rural areas. In agriculture, education is essential to improve food security, rural employment, and to reduce poverty.

It is difficult to transmit information to people that cannot understand traditional text based educational materials. An option is the use of illustration-based materials in which the information is represented using graphics. Manual development of graphical materials, even using traditional computer graphics packages, is a very time consuming process. Those materials usually are general and do not reflect the cultural conditions of the target audience. The approach presented in this work aims at producing illustration based educational materials using an ontology based system. This methodology allows

for development of illustrations that can be adjusted (localized) to specific characteristics of the audience.

Ontology is a formal, explicit specification of a conceptualization within a domain, where conceptualization refers to an abstract model of some phenomenon. An irrigation ontology was developed to organize data and organize concepts in the irrigation and water management domains, while allowing browsing, search, tagging and classification of information. This ontology consists of more than 270 terms and 300 relationships. The irrigation ontology also stores vector graphics that can be localized. This means that they can be adapted to represent more properly the conditions of the audience that will use the educational materials. Trial versions of the illustration based educational materials were evaluated in El Salvador. The levels of understanding of the message being transmitted by the illustrations, as well as each illustration (e.g., color, size, level of detail), were evaluated.

The main advantage of using an irrigation ontology to model and manage irrigation and water management information is that the content can be separated from the format, meaning that the same content can be presented in multiple formats like web pages, printed text, presentations, or PDF files.

CHAPTER 1
INTRODUCTION

Education, Literacy, and Agricultural Development

As a means of production, way of life and source of food, agriculture in developing countries has been suffering irreparably over the last decade. While this is happening, there is an increasing realization that our rural farmers, NGOs, governments and researchers simply cannot afford to continue wasting resources pursuing development and research goals that cannot tangibly change the lives of rural farmers and become a permanent part of their lives (Mukhwana, 2000).

There is a need to find more sustainable methods, approaches and technologies of food production that can increase agricultural productivity and income while protecting and enhancing the environment (Mukhwana, 2000). The total population in West Africa tripled between 1950 and 2000. In 1950, the urban/rural population ratio was 1:10, in 1990 it was 1:3.4 and in 2005, 42% of the population was living in urban areas (UNFPA, 2005). With the exception of Burkina Faso, per capita food intake is diminishing. Increasing population density and pressure on the land have altered traditional production patterns, and sustained agricultural production is being threatened (Lindley et al. 1996). What matters most for economic development in Africa is the capability of rural people to be efficient producers given their natural resource base. There is little doubt that economic and social development, and the benefits that accrue such as improved nutrition and health, require an educated populace (Lindley et al. 1996). No country has become developed without well-educated people and a strong agricultural base that provides food security (Lindley et al. 1996).

The improvement of a country's human resource capacity for productivity is a pre-requisite for social and economic development. In the agricultural sector, formal and non-formal education are both essential for reducing poverty, for improving food security and rural employment and reducing poverty (Lindley et al. 1996). Non-formal agricultural education, often provided by both public and private extension services, is needed for training of farmers, farm families and workers and for capacity building in a wide range of rural organizations and groups (Lindley et al. 1996).

It is increasingly clear that extension workers need better training in both technical agriculture and the extension methods necessary to disseminate production technologies to the thousands of small-scale farmers who need them (Lindley et al. 1996). Most of the available empirical data that testify to the link among education, literacy and agricultural productivity are based on studies of formal schooling (UNESCO, 1994; Lauglo 2001, Wilfred Monte, 2002). Education is an essential prerequisite for reducing poverty, improving agriculture and the living conditions of rural people and building a food-secure world (ERP, 2005).

Literacy

The term “literacy” has always been used to denote a certain ability or inability. For example, a person who cannot use a computer will be referred to as being “computer illiterate or a person who cannot use money properly will be referred to as “economically illiterate.” These examples suggest that the term illiteracy can be seen as being relative to a certain situation (Williams, 2001).

The American Federal National Literacy Act of 1991 defines literacy as “having an ability to read, write, speak English, compute, and solve problems to achieve and function in a job and in society” (Williams, 2001).

Adult literacy can be defined in different ways. Two definitions will be used in this work. The United Nations definition states that a literate adult is “a person aged 15 or over who can read and write” (UNESCO, 2000). The Central Intelligence Agency’s (CIA, 2004) Factbook considers a literate adult to be “a person over 10 years who can read and write”.

Because developing countries are struggling to keep up with citizens demands for basic needs, being literate becomes a luxury in a situation of scarce resources (Williams, 2001). Estimates and projections collated by the UNESCO’s (2000) Institute for Statistics show a steady fall in the number of illiterate adults from 22.4% of the world's population in 1995 to 20.3% in 2000. This means that the number of illiterate adults fell from an estimated 872 million in 1995 to 862 million in 2000. Based on current trends, the Institute estimates this should drop to 824 million, or 16.5%, by 2010. Still these numbers are high, and most of the illiterate are poor, farmers, and female, living in areas away from the urban centers, with little or no access to education, not to say technology (i.e., electricity, telecommunications).

The problems of literacy relate not only to the governments’ organizational structure, teaching material, languages barriers, subjects matter, teaching and the training of facilitators, but more importantly to the way literacy is conceptualized (UNESCO, 1997). In any development activity people need to attain these successive levels of skill, and work out --with those in charge of the financial or institutional elements-- a pedagogy by which people can acquire a skill, apply it and acquire the next skill (UNESCO, 1997).

Despite the increase in the world population, great strides have been made to increase literacy, though there are sharp differences between industrialized and developing countries. The growth in the number of literate men and women in the world is expected to continue for the foreseeable future. Nevertheless the number of illiterate adults has remained at about 885 million since 1980, with females still outnumbering males (UNESCO, 1997).

Literacy in Latin America

Today nearly 90% of Latin American/Caribbean adults can read and write but poor education systems continue to generate new illiterates. According to the latest estimations by the UNESCO’s (1999) Institute for Statistics, the region's overall illiteracy rate is 1%, compared to 40% in sub-Saharan Africa and 45% in South Asia. Latin America and the Caribbean's relatively good performance, however, masks huge disparities within and between nations. Countries like Argentina, Trinidad and Tobago, Bahamas, Cuba and Uruguay have illiteracy rates of less than 5%. But 13% of Brazilians and almost a third of Guatemalan adults cannot read or write.

A glance at absolute numbers reveals the millions of men and women who, because they have not mastered basic reading and writing skills, are deprived of the opportunity to enter the labor market or become full-fledged citizens. Some 39 million adults in the region are illiterate, and Brazil's 13% illiteracy rate actually represents roughly 16 million people. The bulk of these illiterates can be found in rural areas, among ethnic minorities and the poor. Particular emphasis must be given to dealing with issues of marginalization and equity, such as those affecting girls and women, and people in rural areas (UNESCO, 1997).

Literacy in Africa

As in many developing nations, illiteracy is very high in sub-Saharan Africa. In fact it is a region with the world's highest illiteracy rate (54%). However, there is a considerable difference from one country to another. In 1997, in countries such as Kenya, Tanzania, Zimbabwe, Botswana and South Africa the literacy rate is about 70%, while in countries such as Uganda, Malawi, Burundi and Rwanda the literacy rates are below 49%. Southern African countries, as with many Third World countries, expanded their education systems rapidly in the 1960s and 1970s (Walters and Watters, 2001). Is a lot of enthusiasm in literacy work and a growing realization that literacy is crucial in the context of integrated programs for imparting messages on population, health, and agriculture and in the struggle to escape poverty (UNESCO, 1997). In geographical terms, the northern region is the poorest. Food security is likely to be a problem to poor households despite the statements, which refer to fertile lands and abundant food supplies (World Bank Report, 1995).

Literacy in the Arab States

Illiteracy remains a serious problem in the Arab region, where the number of illiterate adults reaches more than 65 million people. For men the rate has fallen from 45% in 1980 to 23% in 1995; for women it has fallen from 71% to 56%, though several of the less developed Arab States are still encountering difficulties (UNESCO, 1997). On average only about 63% of the total adult population in the Arab States can read and write. This is one of the lowest adult literacy rates in the world. Literacy levels are below the regional average in Egypt, Mauritania, Morocco, the Sudan and Yemen, and are about

90% or higher in Jordan, the Palestinian Autonomous Territories and Qatar (EFA, 2006a). What makes the matter worse is the existing and increasing gender inequality in access to education.

Literacy in Asia

Asia is the largest continent. By 2000 the population of Asia was 3,688 million, about 60% of the world's total population (UNESCO, 2000). The literacy data for Asia are divided in three major regions: Central Asia with an adult literacy rate of 99%, East Asia and the Pacific at 91%, and South and West Asia at 58%. As with the Arab states, the intra-region variation is high. Some of the causes of the differences are economic development, previous and past socio-political conditions, and to a lesser degree geographic situation (EFA, 2006b). The illiteracy rate in Asia is higher than the world average and other regions except for Africa.

Teaching Agriculture to Adults

The modernization theory advocated, in the early 1960s, a large expansion of schooling based on the human capital theory, which saw education as a productive investment essential for economic growth. This view reinforced the understanding that less developed countries were undeveloped because of their basic characteristics, including their poor education and skills levels (Walters and Watters, 2001). Adult education is embedded in the political, social, cultural and economic processes of society. The information above suggests that the nature of adult education policies, programs and practices reflects the interests and values of different social groups, and the distribution of power and influence in the society (Walters and Watters, 2001).

In the last 20 years most developing countries have embarked on numerous adult education programs that focused on skills development in both the formal and informal economies. Within the context of globalized economies, economic development and adult education, or adult learning, become even more urgent and complex (Walters and Watters, 2001).

Agricultural education projects are based on teaching a topic to a determined audience. Teaching, like other forms of information transmission, is a communication process. Usually the teacher *sends* a verbal *message*, which contains some *information*, to the learners who are expected to *receive* it and integrate it into their existing knowledge.

This process is not so simple. First, teachers have to *encode* their thoughts into words and/or other forms of communication. Then students have to *decode* the message; this means they have to make sense of it (Blum, 1996).

To make sure that this actually happens, teachers can do two things: strengthen their verbal messages by additional means such as visual teaching aids, thus enabling students to receive the message over two or more parallel communication lines (the ear and the eye). However, the two parallel messages must be matched in order to have an amplifying effect. If they are not, they create confusion ("noise," in the language of communication) (Blum, 1996). Performing the activity and the educational materials can help the learner remember the concepts taught, these are the parallel messages when dealing with illiterate audiences.

Agricultural teachers have an advantage when teaching in the field. Students can observe by themselves and through different channels of perception a situation that the teacher might find difficult to put (encode) into words. Messages that are received by the students are filtered and stored temporarily in the short-term memory. They are forgotten after about 30 seconds if they cannot be kept in mind or transferred to the long-term memory. Thus, we forget casual telephone numbers very quickly unless we make an intellectual effort to remember them. The long-term memory receives new information better when it fits into an already existing framework of concepts. Incomprehensible and unclear messages are not easily stored in the long-term memory and they are quickly forgotten. Competing verbal and audiovisual messages are difficult to cope with. Showing something to students and talking about something different weakens the transmission of the message (Blum, 1996), hence, the importance of content-relevant educational materials that are easy to comprehend to the audience (learners).

The transfer of *technical skills* seems to be even more restricted. In most cases it was found that, with practice, the speed and quality of a given technical task could be improved, but that this does not help to improve other practices. However, the transfer of practical training can be enhanced to some extent when students understand the principles that underlie the practices. In agriculture, this means that we can enhance the teaching of practices when we make sure that students understand why they should do things the way they are taught (Blum, 1996).

When learning needs reinforcement, educators can use an array of educational materials. However, when dealing with illiterate audiences the available materials are hard to find, and if available they are not always relevant to the audience. Illustration-based educational materials are the best option when trying to provide support materials for illiterate people.

Agricultural Education Using Images

Most of the communication means containing images are especially appropriate for a public that has received little or no formal education. Its visual nature attracts attention and helps the message to be transmitted at a glance (De Paolis, 1994). The images have to generate participation and identification of the observer with the subject or object shown.

When referring to images there has to be a distinction between photographs and illustrations or drawings. That difference will be fundamental to differentiate the iconic cultures; some cultures may identify photographs more easily than drawings or vice versa (De Paolis, 1994). However, that separation might also be economical and technological given the differences in printing costs and equipments needed for photographs and drawings. The different elements of the messages have to be composed in a way to contribute to producing certain effects on the recipient (audience).

Justification

A difficulty commonly encountered in the preparation of illustration-based educational materials is the preparation of the artwork, especially when the material is intended for an ethnic or language group or groups other than the one creating the material. Over the years, attempts have been made to supply visual models that might make the job of drawing visuals easier for workers with limited training. Another problem often encountered is the difficulty in finding experienced personnel to prepare the materials quickly and easily. It has also proven difficult to adapt (localize) materials which have been successful in one region or country to another ethnically or culturally different one because the models do not lend themselves to change: instead, project workers use available materials that are not appropriate ,or have to create educational materials from scratch. With the increasing numbers of computers being used in the field there is growing demand for a simpler and more direct system to produce appropriate materials.

The user should be able to choose among the images that convey the desired message, adapt them as necessary and print them out in a very short time. The images should be realistic and as detailed as necessary.

The main advantage of such a system is that the same images could be easily changed for a variety of different uses and formats. Any changes on the illustrations can be easily and quickly done on the computer screen. There is no need to make entirely new drawings when the audience changes. The image bank can be made available to several organizations.

The general steps that have to be followed to develop educational illustrations are;

1. Decide on the form, context, and use of the illustrations based on an understanding of the audience (their attitudes and practices) and the development of strategies aimed at changing behavior in line with the established goals of the project.

2. Collect images (the easiest would be to use images already existing in an “image bank,”) from other materials with the respective permission, or scenes that could be photographed.

3. Adapt the existing materials to make them culturally appropriate for the audience’s needs, interest and conditions.

4. Prepare the educational materials containing the illustrations in the desired format, and reproduce the materials.

Presently, this process is mostly done manually and can be very time consuming. Another drawback is that resources are wasted since materials developed in other projects are not adapted or reused in other applications. The use of a computer assisted process to produce, store, and manage the illustrations, and then develop the educational materials, would make this process easier and more efficient.

The potentials of this type of system to produce educational materials are just being recognized. Aside from saving time and money, using the computer also allows the production of specialized illustrations from the image bank. Handouts and flyers can be produced from images in the bank and produced in small numbers on a printer or photocopy machine. High quality small editions of training materials can be produced easily and quickly for workshops and seminars. The use of computer graphics to produce project support materials could simplify a costly and complex task. This would bring enormous potential benefits to projects developing educational and instructional support materials (Tisa, 1991).

Overall Objectives of the Study

The main objective of this study is to develop an ontology for the irrigation and water management domain. Ontologies have been proposed to solve problems that arise from using different terminology to refer to the same concept or using the same term to refer to different concepts (Beck and Pinto, 2002). Ontologies can be used to organize metadata and to order concepts in a given domain, while allowing browsing, search, tagging and classification of documents.

Secondary objectives of this study are:

- To adapt a process to develop ontologies in the agricultural domain. Create an ontology for irrigation related materials. The information contained in the ontology will focus on the knowledge needed in developing countries to improve irrigation practices.
- To present the information on more than one language (i.e., English, Spanish) and other characteristics that will allow localization of the materials to be developed.
- To find a technology capable of creating didactic manuals “on-the-fly” for extension education, and to print those materials “on-demand.”
- To evaluate the illustration-based educational materials on the field.
- To demonstrate the necessity of a tool to create didactic manuals especially for people with low literacy/education levels, or little knowledge of the topics. This will include, illiterate people (mainly in developing countries), people without knowledge of English (i.e., foreign agricultural workers), children (i.e., 4-H).

Methodology

This project focuses on the creation of an irrigation domain ontology. The ontology includes text, pictures and drawings related mainly to irrigation and water management. The content is organized by topics (i.e., surface irrigation, water conservation, etc). The use of this tool potentially will avoid many of the delays, costs, and inventory issues associated with traditional development of educational materials. This could facilitate the transfer of information from the extension specialists to extension agents to final client.

The base for a successful implementation of an ontology system is a narrow and clearly defined knowledge domain; the choice of subject is crucial to a successful implementation. The process to create the ontology includes the collection of all relevant information for all topics that the irrigation ontology will cover. The information includes text and other visual aids (e.g., pictures, diagrams, drawings).

Since the objective of this work is to create educational materials for people with low levels of education, the next step is to develop drawings that will be used to explain some processes and ideas to people that are not able to read. A big challenge to this project is to achieve the automation of the process of creating situation and culture specific drawings from digital pictures.

The end product will be a tool that facilitates the creation, storage and management of content in multiple formats. The ontology-based tool will also allow localization of multiple properties of graphics and text. Finally, it will permit the development of educational materials ranging from manuals containing just text and technical language for the extension agents, and educational materials with visual aids and some brief text for illiterate learners.

The field evaluation of the illustrations was done in a rural area in El Salvador. It consisted of the use of closed and open-ended questions. The data collected was helpful making changes and improvements in the content, illustrations and format of the educational materials. The comments and results were incorporated in the final development of the graphic materials.

Expected Outcomes

The main outcome of this project was the creation of an irrigation ontology that allows the storage of multilingual text and visual aids; the data stored should be easily manipulated (allow for localization) in order to create easy to understand and reproduce educational materials.

Organization of the Dissertation

This dissertation is organized in six chapters. Chapter 1 includes a literature review of the main concepts utilized, also in this chapter the justification, objectives, and methodology for the study are presented. The ontology modeling methodology is presented in two chapters; specification, conceptualization, and evaluation are explained in Chapter 2, while formalization and implementation are presented in Chapter 3. Chapter 4 shows the incorporation of vector graphics into the irrigation ontology to allow the development of illustration-based educational materials. The field evaluation of the educational materials conducted in El Salvador (Central America) is presented in Chapter 5. Finally a summary of the dissertation and conclusions are presented in Chapter 6.

CHAPTER 2
IRRIGATION ONTOLOGY MODELING

Introduction

An increasing number of information resources require improved information management systems. There are several approaches to organize information; the most common are glossaries and thesauri. Glossaries are lists of terms with their meanings specified as natural language statements. Thesauri provide descriptions and additional semantics between terms like synonym and antonym relationships.

A basic ontology can be very similar to a thesaurus. However, the ontology is not limited to the types of relationships present in a thesaurus; instead it has a series of features that improve its search and conceptual capabilities. An ontology can be regarded as a particular knowledge base, describing facts assumed to be true by a group of users of a certain domain.

Thesauri

Thesauri provide only very basic modeling paradigms and no knowledge can be extracted from a thesaurus except simple keyword relationships (Lauser, 2004). A thesaurus is a networked collection of controlled vocabulary terms based on hierarchical, equivalent and associative relationships. Thesauri are limited in the inter concepts relationships that can be represented. Hence, the specific information that can be extracted is also limited. A thesaurus is based on concepts expressed as terms and some relationships among those terms. Term is a word or expression that has a precise meaning in some science, art, profession, or subject. The types of relationships available for the thesaurus may require for the terms to be arranged in categories that do not form a logical hierarchy. Two examples are presented, AGROVOC (2005) from the United Nations' Food and Agricultural Organization (Figure 2-1), and the United States National Agricultural Library Thesauri (NALT, 2005) (Figure 2-2).

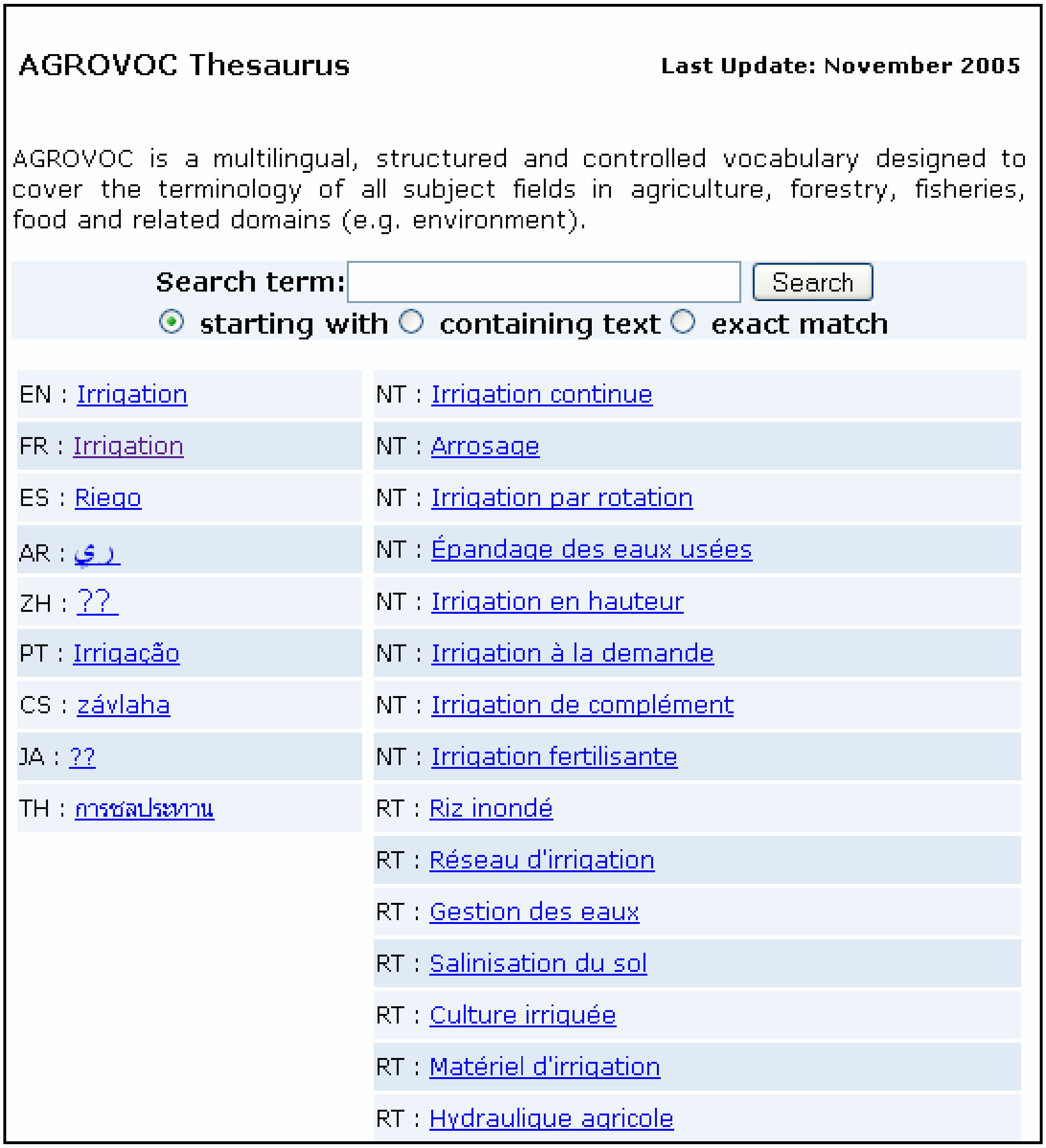


Figure 2-1. View of the AGROVOC Thesaurus

In Figure 2-1, in the left column a list of terms in different languages that correspond to the term "irrigation" can be observed. In the right column another set of terms is presented, preceded by NT, or RT. NT is used for narrower term, this means that it is a term more specific than irrigation. RT means related term; it is a term that is not too closely related to “irrigation.”

The existing relationships are designed to give the terms semantic logic, rather than to indicate relationships like “part of,” or “belongs to,” that are common in ontologies. The basic relationships that can be encountered in a Thesaurus are hierarchical “Broader Term” (BT) and “Narrower Term” (NT), equivalent “Use Preferred Term” (USE) and “Used for” (UF), and associative relationships “Related Terms” (RT) (Hassen, et al., 2004).

Figure 2-2. View of the NAL Thesaurus

Apart from the display of the related terms, the only difference between the NAL thesaurus and AGROVOC is that the former offers a brief definition for some of the terms that it contains.

The main objective of a thesaurus is to create a hierarchy of related terms. Terms could be defined as the “names” of the concepts. A thesaurus basically takes taxonomies (a classification that arranges the terms into a hierarchy) and extends them allowing other statements to be made about the terms. Thesauri allow the search of terms in a structured manner; they also allow the search of related terms relatively easily, since all related terms should be located close to each other.

Ontology

Ontology is a formal, shared, explicit specification of a conceptualization within a domain (Gruber, 1993). Conceptualization refers to an abstract model of some phenomenon. Shared means that an ontology captures consensual knowledge accepted by a group (Benjamins et al., 2002). The features contained in an ontology are classes, subclasses, instances, properties, and complex (inter) relationships between terms. Ontology is a more complete structure to describe a domain’s concepts as well as multiple relationships among those concepts. An ontology formally describes a domain (Antoniou and van Harmelen, 2004); it provides a generic way to reuse and share content across applications and groups (Pinto and Martins, 2001). However, it is important to remark that the model can only be considered an ontology if it is a shared and consensual knowledge model agreed upon by a community (Hassen, et al., 2004; Antoniou and van Harmelen, 2004).

A formal ontology is a controlled vocabulary expressed in an ontology representation language, a model for describing the world that consists of a set of concepts, descriptions or properties, and relationships. This language has a grammar for using vocabulary terms to express something meaningful within a specified domain of interest. An ontology representation of the domain should try to be a resemblance of the real world complexities. The interrelations present between terms in an ontology allow the search tool to produce a list of related and relevant terms. All the associated information related to the term being search is retrieved. An ontology typically is shared or built with the collaboration of domain experts (Pinto and Martins, 2001).

Ontologies are widely used in Knowledge Engineering, Artificial Intelligence, and Computer Science, in applications related to knowledge management, natural language processing, e-commerce, intelligent integration information, information retrieval, database design and integration, and education (Gómez-Pérez et al., 2004).
Ontologies have been proposed to solve problems that arise from using different terminology to refer to the same concept or using the same term to refer to different concepts (Beck and Pinto, 2002). The term "ontology" is a branch of Philosophy that deals with the nature and organization of reality. Aristotle first defined it as "the science of being as such" (Guarino and Giaretta, 1995). All type of communications, including the internet with its great capacity to disseminate information, need a shared vocabulary. Even a simple list of terms can be viewed as an ontology, since it is a set of definitions that helps to better understand a topic (Passin, 2004).

The Semantic Web is based on ontologies for organizing large collections of knowledge. Ontologies allow searching information distributed across multiple sites on the web, and in different languages (Beck and Pinto, 2002). The Semantic Web provides a common framework that allows data to be shared and reused across application, enterprise, and community boundaries. It is an extension of the current web and it contains the information which is given well-defined meaning, better enabling computers and people to work in cooperation (W3C, 2001a). The way that knowledge is stored and organized influences the retrieval problem (Beck and Pinto, 2002). Conventional information retrieval technologies like the ones used in web search engines are not as precise and do not always retrieve relevant information.

The knowledge organization in concepts and the relationships among those concepts within a domain is what improves the searching capabilities of an ontology (Passin, 2004). Information resources are attached to the ontology terms to create a complete database. As a result, users can perform queries to retrieve the specified information (Beck and Pinto, 2002).

Research ontologies are becoming more common, as a tool to describe a vocabulary's meaning and the relations among those meanings. The simplest ontology describes a hierarchy of concepts related by assumed relationships. They aim at improving the communication between computers and humans. Ontologies have applications in software development, research, and database applications. Reusability means that the ontology should allow knowledge sharing and reuse. An ontology can be used to organize metadata and to provide an order to concepts in a given domain, while allowing browsing, search, tagging and classification of documents. Knowledge acquisition permits the ontology to model the domain of the application. Reliability and maintenance allows consistency check for software development.

Ontology Classification

According to their accuracy in characterizing the conceptualization to which they commit, the ontologies are divided into fine-grained and coarse. For this project a coarse ontology was developed. This means that the ontology is based on terms and concepts already agreed by users, and it is designed to support limited and specific services. Ontologies can also be classified by the level of generality as top-level ontologies, domain and task ontologies, and application ontologies (Guarino, 1998). The irrigation ontology built here is a domain ontology; this means that it describes a vocabulary related to a generic domain (irrigation) on which it focuses.

Ontology Languages

A couple of the languages (Beck and Pinto, 2002; Passin, 2004) used to define ontologies are the Resource Description Framework (RDF), and DARPA, the Agent Markup Language & Ontology Interchange Language. RDF (W3C, 2002) has developed on top of the extensible markup language (XML) (W3C, 2004b) for the purpose of describing web resources. The DARPA Agent Markup Language & Ontology Interchange Language (DAML+OIL) that is being developed for building more complex ontologies (DAML, 2004; W3C 2001c). Both are based in semantic networks, however, some of them differ in their level of expressiveness, and this affects the kinds of inferences that can be applied.

Ontology Editors

Ontology editors (or builders) were developed to help create ontologies in different domains. Some of the ontology editors are OntoBroker, Protégé-2000, Ontolingua, and ObjectEditor. OntoBroker created by the Institute for Applied Computer Science and Formal Description Methods (OntoBroker, 2004) uses HTML, XML, and RDF. Protégé-2000 developed by the Knowledge Modeling Group (KMG) at Stanford University, allows the user to create a domain ontology. Ontolingua Server (http://www-ksl-svc.stanford.edu:5915/) is widely used. It maintains a large library of ontologies that can be reused, and permits collaboration among various authors (Farquhar et al., 1995). The tool used to construct the irrigation ontology was the ObjectEditor, a Web-based tool for constructing ontologies within specific domains (http://orb.ifas.ufl.edu/ObjectEditor/index.html) developed in the Department of Agricultural and Biological Engineering at the University of Florida (Beck, 2003a; 2003b).

Objectives

The objectives of this chapter are 1) to select a modeling methodology for a domain ontology, 2) to use this methodology to define and model an irrigation ontology, and 3) to compare the irrigation ontology with some existing thesauri.

Methodology

There are several methodologies to build ontologies, however the one that best fits the irrigation domain ontology is presented below. There are some typical steps that should be followed to construct an ontology (Uschold and King, 1995; Pinto and Martins, 2001):

- Specification
- Conceptualization
- Formalization
- Implementation
- Evaluation, maintenance, and documentation.

These steps are represented in the ontology life cycle diagram (Figure 2-2); they are related to most software engineering activities. Various authors have developed some variations of the life cycle. One of the most accepted is the evolving prototyping life cycle (or evolutionary cycle).

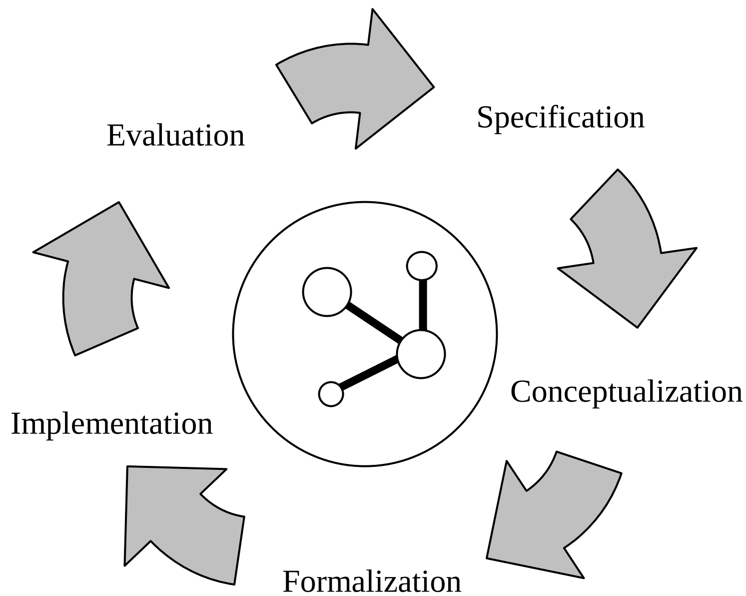


Figure 2-2. Activities of the ontology development life cycle

In this cycle the developer can go back from any stage to any stage of the development process. This means that the ontology can be modified until the evaluation is satisfactory and all the objectives of the ontology are met (Beck and Pinto, 2002).

Ontology Specification

Ontology specification refers to the definition of the scope of the ontology. The scope of the ontology presented in this work is irrigation knowledge domain, related to small farmers’ irrigation systems. One question that should be asked at this point is: Why develop an ontology? Some of the reasons for the development of an ontology for specific domain are (McGuinness and Fridman Noy, 2001):

- To provide a common structure of information within a domain
- To make domain assumption explicit
- To allow the reuse of domain knowledge
- To analyze domain knowledge

Ontology Conceptualization

One of the basic applications of ontologies is having an agreed set of terms and concepts organized in order to facilitate information use by humans and computers. Uschols and Gruninger (1996) recommend having brainstorming sessions to compile relevant terms and phrases that may later constitute concepts in the ontology. The structure of the ontology becomes apparent by grouping the terms in related areas. It is also important to consider closely related or equivalent terms to avoid duplication of concepts. An ontology should effectively minimize ambiguity and if possible, all definitions should be defined in natural language. In some cases examples may be needed to clarify definitions (Uschols and Gruninger, 1996).

Knowledge acquisition, the next step after the definition of the domain and scope of the ontology is the definition of classes that describe concepts in the domain (McGuinness and Fridman Noy, 2001). A top-down approach was selected, over a bottom-top or a combination, to define the hierarchy of classes and subclasses, this means that the classes (more general terms) were first defined and then the subclasses (more specialized terms) and so on. This structure implies that work should start in the most fundamental terms before moving to the more abstract terms within a domain (Uschols and Gruninger, 1996). Once appropriate terms were defined, then their properties were determined to describe the internal structure of the concepts. All terms have to be related to other classes (as concepts are related to other concepts within the domain); ObjectEditor allows four types of relationships: “association,” “part,” “sequence,” and “generalization.”

Ontology Formalization and Implementation

Chapter 3 covers the formalization and implementation process. A detailed explanation of all the processes is given; examples from the irrigation ontology are used to illustrate the ideas and some modeling issues.

Ontology Documentation, Evaluation, and Maintenance

Continuous evaluation of the ontology is important in order to avoid problems or make corrections before it is too costly to do it. The following evaluation guidelines should be considered (McGuinness and Fridman Noy, 2001; Uschols and Gruninger, 1996):

- Develop a natural language (e.g., English) definition of the ontology
- Use common and agreed terms (e.g., standards, dictionaries)
- Notice relationships with other terms (synonyms referring to the same concept)
- Avoid circular reference when defining terms
- Use clear and concise definitions
- Provide examples to explain concepts when needed

Guidelines to document the ontology are desirable. All important assumptions about the main concepts defined in the ontology should be documented (Uschols and Gruninger, 1996). This documentation could be then used as metadata. Maintenance is a constant process with any ontology. Ontologies are continuously confronted with evolution problems, and maintenance is necessary to ensure the reliability of the ontology.

The irrigation ontology was also evaluated against the NALT, AGROVOC and IWMI descriptors. This evaluation was conducted to check how well the irrigation ontology covers the terms within the irrigation/water management domain. A list with all the ontology terms divided by topics was compared against the terms contained in AGROVOC, NALT, and IWMI descriptor list.

Application of Modeling Methodology to Development of Irrigation Ontology

The modeling of the irrigation ontology was conducted using previously described general steps: specification, conceptualization, formalization, implementation, and evaluation. Developing an irrigation ontology is not a goal in itself. The main objective is the use of the defined sets of terms and their structure for a particular purpose. As a consequence there is not unique ontology of a specific domain (irrigation in this case). An ontology is an abstraction of a particular domain, and there are always alternatives. What was included in the irrigation ontology was determined by the final use of the ontology. However, the irrigation ontology is still general enough to allow expansion and shareability.

To help with the specification of the irrigation ontology some questions have to be asked; the answers to these questions guide the rest of the modeling process:

1) *Why an ontology?* An ontology offers versatility that other knowledge management systems (e.g., thesauri) cannot provide. Ontologies can be modeled to fit the user necessities while being malleable enough to be adapted and shared for other uses. Ontologies offer a better way to organize information, and manage content.

2) *What will be the objectives (main and secondary) of the irrigation ontology?* The objectives for development if irrigation ontology were early defined as:

- Evaluate if the ontology can be used to develop educational materials.
- Collect and store irrigation and water management related information, mainly focus at the development of educational materials for small farmers with low levels of literacy.
- Store this information with a common structure that can be reused in other applications.
- Offer tools for the development of multi-format educational materials for broad audiences.

3) *What is the scope of the irrigation ontology?* The irrigation and water management domain is very broad, so limitations have to be created for the ontology. The objectives of the ontology help limit the ontology's scope, in this case subtopics that are closely related to small farm irrigation. Examples can be water harvesting, soil conservation, low cost irrigation systems, etc.

During the specification process it is important to remember that the final application defines the domain of the ontology. Limitations out of the control of the experts and modelers should also be considered; in the case of the irrigation ontology available time and labor were the limits. By having these factors in mind the ontology development process can be guided toward the ontology's objectives.

Conceptualization covers the process of collecting the information (knowledge) that will be part of the ontology's content. At this point it is important to remember that the ontology has to have a finite scope and purpose for its content. The modeling methodology aims at representing the "real world" in logical terms using a given ontology software editor, in this case ObjectEditor. A flow chart of the conceptualization process is presented in Figure 2-3; it explains the flow from data acquisition to the incorporation of the term into the ObjectEditor.

Considering the objectives and limits of the irrigation ontology, the first step toward the actual definition of the irrigation ontology was to write down an unstructured list of all the relevant terms expected to appear in the ontology. The list of terms relevant to the irrigation domain was developed with information extracted from sources such as the Land and Water Development Division of the Food and Agricultural Organization (LWD, 2005), American Society of Agricultural and Biological Engineers (ASABE)

(ASABE, 2005), United States National Agricultural Library Thesaurus (NALT) (NATL, 2005), and the Extension Data Information Source (EDIS) from the University of Florida (EDIS, 2005). A group of specialists from the University of Florida was also involved in the knowledge modeling process. It is important to mention that every individual had a personal ontology; meaning that each one had a particular perception of the knowledge about the irrigation domain. In order to create a common ontology from the perceptions of individual experts, much group discussion was required to arrive to a common set of terms and their definitions.

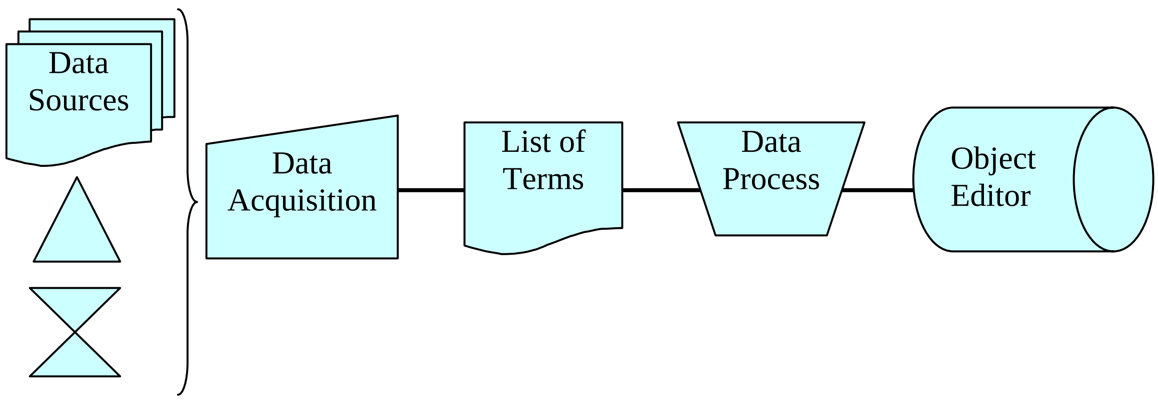


Figure 2-3. Diagram representing the conceptualization process

This complex process is illustrated with a simplified example. The first step was to select a representative sample of irrigation related terms from the literature:

- Water management
- Precipitation
- Evapotranspiration
- Soil
- Aquifer
- Irrigation scheduling
- Microirrigation
- Infiltration
- River

The next step was to group the common terms together (conceptual clustering).

- precipitation, evapotranspiration
- soil, infiltration
- aquifer, river
- water management, irrigation scheduling

From here groups of related terms were created. Each group was named by the general concept it represents. The groups were be modeled as “modules” in ObjectEditor to facilitate its display.

- Weather
- Soil
- Water Resources
- Water Management

The groups were created according to the relevance they have to the ontology developers and modelers. As new terms entered the collection, new groups were defined if the existing ones were not adequate.

After the identification of the relevant terms, these terms were organized in a taxonomic hierarchy. The irrigation ontology modeling methodology followed a top-down approach (Prieto-Diaz, 2002). This means that the more general terms were placed higher in the hierarchy, and the terms became more specific towards the lower levels of the ontology. The irrigation ontology was classified following existing classification from the literature, and by agreement among the experts involved in the modeling of the irrigation ontology.

For topics like “system design” or “irrigation efficiency,” the process of selecting the terms, definitions, and the determination of relationships among those concepts was iterative, meaning that the process had to be repeated multiple times until all the experts agreed on a common irrigation ontology. For other topics like “weather,” “plant,” or "soil," the classification process was much simpler, having only to follow pre-existing classifications, from the sources sited above.

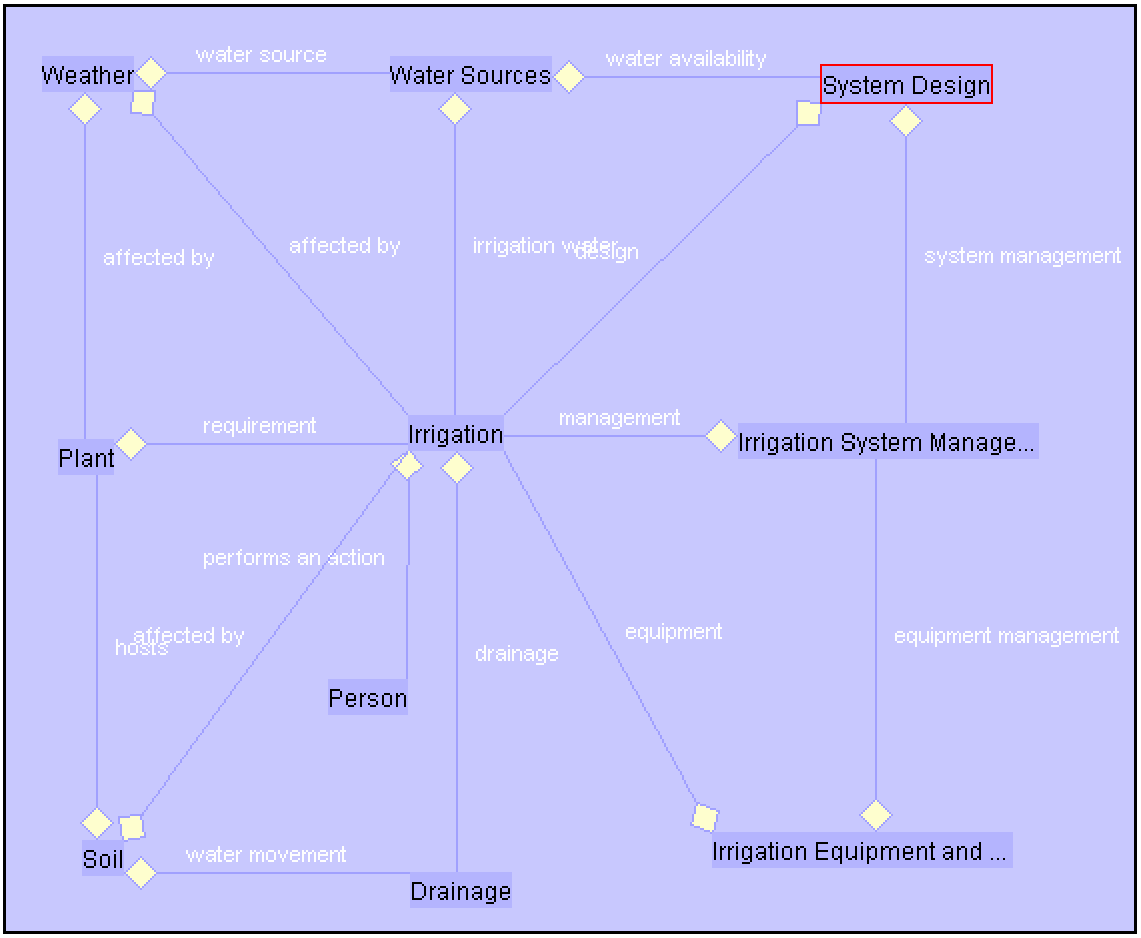


Figure 2-4. Main topics covered by the Irrigation Ontology in ObjectEditor

The documentation part consisted of recording the sources of the information collected and incorporated into the irrigation ontology. It also included any comments made during the modeling process. Evaluation and maintenance of the ontology were interrelated. Below are some questions that were used during the evaluation process:

- Does a selected term fit the ontology specification?
- Does the location of a term in the hierarchy make sense?
- Do the gloss and definition of the term are in sync with the specific ontology domain?
- Were there any errors during the ontology implementation process? (e.g., was the correct relationship used?)

Errors were corrected as encountered during the evaluation process. This facilitated the maintenance of the irrigation ontology. The continuous evaluation and correction process helped avoid the necessity of larger modifications at the end of the modeling process.

The irrigation ontology was compared to the NALT, AGROVOC thesauri, and IWMI descriptors. At the time of this evaluation the irrigation ontology contained around 270 terms from the irrigation and water management domain. NALT refers to the United States National Agricultural Library Thesaurus (NALT, 2005). The 2006 edition is the fifth edition of the NAL Agricultural Thesaurus, first released in 2002. The total number of terms contained in the NATL is 66,417 with definitions for 2,038 terms. AGROVOC is a multilingual, structured and controlled vocabulary designed to cover the terminology of all subject fields in agriculture, forestry, fisheries, food and related domains. Currently, it works in the following languages: English, French, Spanish, Arabic and Chinese. Other national versions include Czech, Portuguese, Japanese and Thai language versions. German, Italian, Korean, Hungarian, and Slovak language versions of AGROVOC are under construction. As an example, the English version has 28,127 terms, while the Spanish version has 28,123 terms. It was developed by the United Nations' Food and Agricultural Organization (AGROVOC, 2005). An unpublished list of 2,388 irrigation related descriptors provided by the International Water Management Institute (IWMI) in Sri Lanka was also analyzed during this study.

NALT, AGROVOC thesauri, and IWMI descriptors were used to check how well the irrigation ontology covers the terms within the irrigation/water management domain. A manual search of the terms stored in the following sources was performed. The search was conducted using the online search tools for each of the datasets described above. For the evaluation the terms were divided into nine main areas or topics: Irrigation Water Sources, Weather, Plant, Soil, Drainage, Chemigation, Irrigation System Design, Irrigation System Management, and Irrigation Equipment and Structures. A list with all the terms included in the irrigation ontology divided by topics was compared against the terms (or synonyms) in AGROVOC, NALT, and IWMI descriptors. The results are presented in Table 2-1 below.

Table 2-1. Comparison by topics of various sources vs. irrigation ontology

Topics	Irrigation Ontology	AGROVOC	IWMI	NALT
	Total # of terms	%	%	%
Irrigation Water Sources	45	20.00	26.67	28.89
Weather	13	53.85	46.15	53.85
Plant	16	68.75	25.00	37.50
Soil	31	64.52	48.39	87.10
Drainage	20	15.00	15.00	10.00
Chemigation	16	6.25	12.50	18.75
Irrigation System Design	41	4.88	2.44	9.76
Irr. System Management	30	23.33	0.00	10.00
Irr. Equip. and Structures	59	0.00	0.00	16.95

Source: Cornejo, 2006

$$\% = \# \text{ Terms}^{1} / \# \text{ Terms in Ontology} * 100 \qquad \text{Equation 2-1}$$

1 Number of terms from AGROVOC or IWMI matching terms in the irrigation ontology.

From Table 2-1 can be observed that AGROVOC, IWMI, and NALT contain a higher percentage of the same terms as the irrigation ontology in three main topics. Those topics are soil, plant, and weather with values ranging from 37.5% to 87%. For the topics more relevant to irrigation like system design, system management, and irrigation equipment, the values range from 0% to 23.3%. Irrigation equipment and structures are the topic where less matches occurred, the only database that had any terms related to this topic was the NALT with 16.95% of the terms.

In Table 2-2 a more general comparison is presented. The total number of terms found in each of the datasets compared to the total number of terms from the irrigation ontology is shown. Again using Equation 2-1 the matched terms from each of the sources were compared to the total number of terms from the Irrigation Ontology (271). IWMI contained 15.8% of the terms, AGROVOC 22.1%, and NALT 27.68%. Even so, the IWMI descriptors in theory should have more irrigation and water management concepts; this set is the one that has fewer of the terms contained in the irrigation ontology

Table 2-2. Comparison of various sources vs. irrigation ontology

Topics	Irrigation Ontology	AGROVOC	IWMI	NALT
Total number of terms	271	60	43	75
Percentage from Irr. Ontology		22.14	15.87	27.68

Source: Cornejo, 2006

Conclusions

The presented methodology for ontology development seems to work well for the irrigation ontology. This framework is generic enough to be used to create other domain ontologies especially within the agricultural field. The irrigation ontology developed using this methodology should fulfill requirements for compatibility and shareability with other ontologies. The above approach made the modeling process very straight forward and it was easily followed by the experts that had little experience with ontology modeling. As stated in the objectives, the domain of the irrigation ontology was very limited. Because of the narrow domain of the irrigation ontology, it was possible to do all the modeling manually. The final irrigation ontology developed in this project has more than 270 terms and 300 relationships however the process was time consuming and required multiple brainstorming sessions for the experts to agree in the final ontology. For larger ontologies an automatic modeling methodology should be developed to expedite this process.

CHAPTER 3
IRRIGATION ONTOLOGY FORMALIZATION AND IMPLEMENTATION

Introduction

Ontologies can be used to support a great variety of tasks in diverse research areas such as knowledge representation, natural language processing, information retrieval, databases, knowledge management, online database integration, digital libraries, geographic information systems, and visual retrieval or multi agent systems. Ontologies enable shared knowledge and reuse where information resources can be communicated between human or software agents. Semantic relationships in ontologies facilitate making statements and asking queries about a subject domain due to the use of conceptualization.

Domain ontologies are reusable in a given specific domain (medical, engineering, law, irrigation, etc.). These ontologies provide vocabularies about concepts within a domain and the relationships among those concepts, about the activities taking place in that domain, and about the theories and principles presented in that domain. There is a clean boundary between domain ontologies and upper-level ontologies. The concepts in domain ontologies are usually specializations of concepts already defined in top-level ontologies, and the same might occur with the relationships (Mizoguchi et al., 1995; van Heijst et al., 1997). Ontologies offer ways of better managing the vast educational resources that have been and are still being developed by organizations such as the U.S. Cooperative Extension Service and United Nations Food and Agricultural Organization. Issues involved in educational resource management include properly identifying (cataloging) each resource, where large numbers of resources exist at many levels of granularity ranging from entire training curriculums to individual lessons or modules to the content of those modules including individual text fragments, images, and other multimedia resources. New authoring tools for generating this content in the context of ontologies, and tools for automatically generating presentations in different formats from shared content are needed. Learning object technologies and standards such as SCORM (Godwin-Jones, 2004) addresses ways of better packaging educational resources into reusable components. SCORM provides a metadata standard for describing learning objects, and includes tags that can reference taxonomic subject classification systems including ontologies (although SCORM itself is not a standard for ontologies). Content management systems are database management systems for storing content in the form of text and other multimedia resources. They store content in a presentation-independent way, and are capable of generating particular presentations from content according to different customizable styles. Combining content management systems with ontologies and with learning object standards leads to an ontology management system that can better organize educational content, facilitate content development, and automate the process of generating educational materials. By using ontologies the information publishing process can be greatly facilitated (Clark, et al 2004).

This approach is being used at the University of Florida on a range of projects, including one on developing educational extension materials to help farmers with limited formal education understand basic principles of irrigation. These educational materials rely heavily on graphic images to illustrate irrigation principles such as creation of water retention structures or general layout of irrigation systems (text is limited or optional because many of the farmers using these materials are illiterate). Furthermore these materials must be adapted to fit local cultural environments. For example, illustrations should change to show crops and agricultural systems local to the area where they are applied, and people should be presented in gender and culturally specific contexts.

An ontology can be the basis of a fully operational database management system (Beck, in press). The concepts and relationships in the ontology also contain primitive data such as text, images, and other multimedia resources that provide additional definition of the concepts. The ontology management system includes a formally defined ontology language which also acts as a data modeling (data definition) language for the database, tools for inspecting and editing the ontology, operations for manipulating the ontology (reasoners), and secondary storage management to support efficient processing of these operations. An ontology manager was used to construct the irrigation ontology along with associated educational content for the domain. Facilities that are part of this system for automatically generating presentations from content are used to create Web-based and printed educational materials. This process is described below.

The process of building the irrigation ontology is an important first step in facilitating shared ontologies for this domain. The process of building working, shared ontologies is still in its infancy. Although established standards for building ontologies now exist, and formal methodologies are well developed, there is a need to build working examples and demonstrate their utility.

The technology for content management, learning objects, and authoring tools for creating educational resources likewise is in a rapid state of evolution. Conventional presentation tools (Microsoft PowerPoint, Adobe Acrobat, and Macromedia Breeze) while widely used, do not attempt to represent content in a presentation independent format, and make no attempt at classifying content in any context, let alone one as sophisticated as an ontology. Building educational materials within an ontology management system hopefully shows the advantages of this approach to better organize educational resources, and gain flexibility in automatically presenting educational materials to meet individual learning styles, native languages, and respect local cultural contexts.

Water management and irrigation is a major component in agricultural technology. Currently no known ontology on irrigation exists. Irrigation ontology was constructed to provide a framework for organizing materials within this specific domain. This ontology can become a starting point for a larger ontology covering irrigation concepts in general. This chapter presents the methodology used to construct the irrigation ontology, briefly describes the tools and environment used to construct the ontology, and provides details of the resulting irrigation ontology including the top-level concepts, and some examples of small domains within the ontology. A complete list of the terms and concepts appearing in the ontology is included in Appendix A.

Objectives

The objectives of this chapter are: 1) Formalization of the irrigation ontology using ObjectEditor. 2) Implementation of the irrigation ontology as part of the ontology modeling process presented in Chapter 2 using ObjectEditor. 3) Identification and discussion of modeling issues encountered during the implementation process.

Ontology Formalization

The steps in the ontology modeling methodology are specification, conceptualization, formalization, implementation, and evaluation. In this chapter formalization and implementation are discussed in detail. The other steps of the irrigation modeling methodology for the irrigation ontology were explained in detail in Chapter 2.

The irrigation ontology was constructed using ObjectEditor a graph-based, Web-based tool (http://orb.ifas.ufl.edu/ObjectEditor/index.html) for constructing ontologies within specific domains developed at the University of Florida, USA (Beck, 2003a, 2003b).

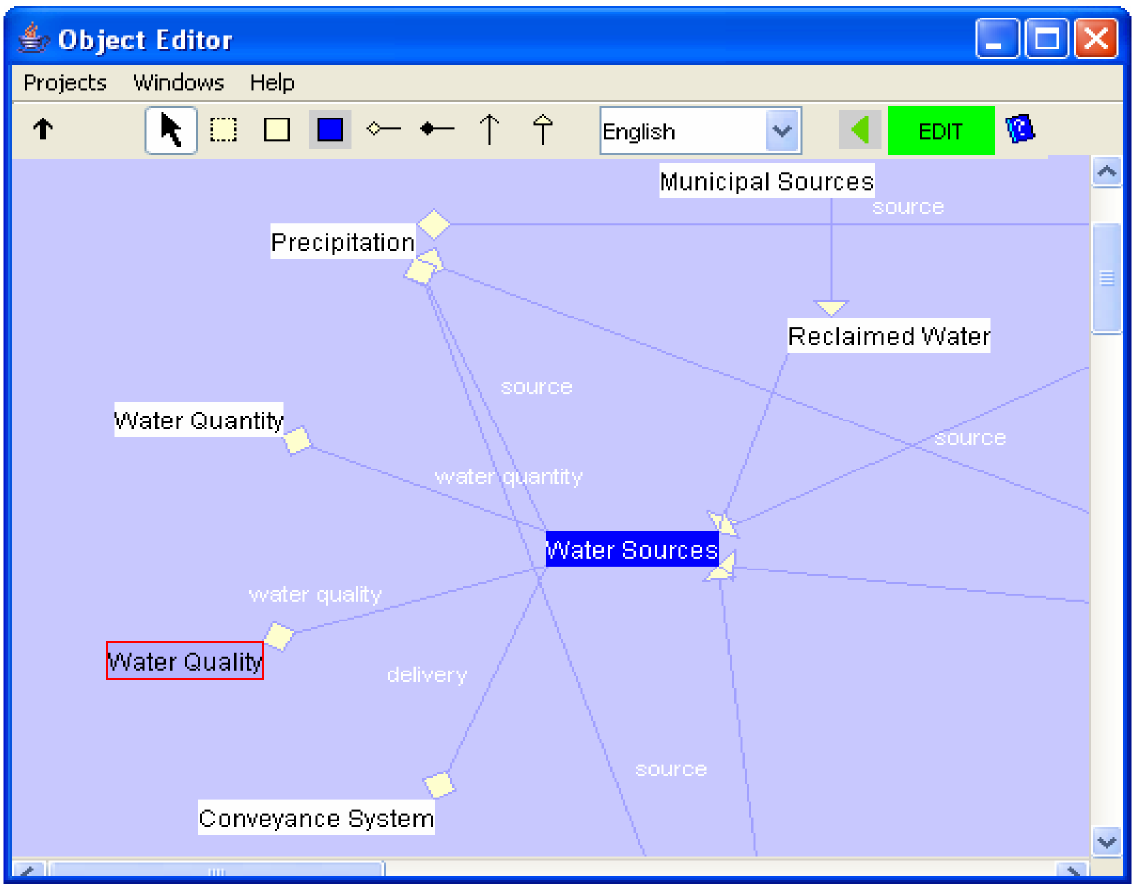


Figure 3-1. View from the ObjectEditor

ObjectEditor can be run on-line in any Web browser (utilizing a Java plug-in) that communicates to a remote server hosting an object-oriented database management system (ObjectStore) (Figure 3-1). ObjectEditor's interface enables users to interact with the ontology in order to define content objects and represent how the objects in a domain are interrelated. ObjectEditor provides a complete ontology management system for editing, viewing, managing physical storage, managing multiple users, and providing reasoning and query processing facilities. Apart from the knowledge modeling that the irrigation ontology represents, ObjectEditor allows the storage and management of ontology content. Content can include text, graphics, and mathematical equations. This content can be rendered in multiple formats depending on the method of presentation. For example, Web pages for personal computers and PDA's, and files (e.g., PDF) for printed media. The separation of content from format typical for an ontology increases the flexibility at publication time, reducing time and work needed to reproduce the same content in different media. The process of developing an irrigation ontology using ObjectEditor is presented here.

ObjectEditor defines its own formalization of definitions and constraints for the terms and relationships used to implement the irrigation ontology. In the irrigation ontology the concepts are represented as classes. Each class can have multiple properties; ObjectEditor supports simple string, rich text, integer, float, range, and images, as data types for the properties. Associations represent relationships between objects. All the subclasses inherit the properties and associations of their superclasses. Each term (class) has a short description or *gloss* (Figure 3-2); this facilitates the definition of the sense of each concept. The gloss can be expressed in multiple languages. The irrigation ontology is implemented in English and Spanish.

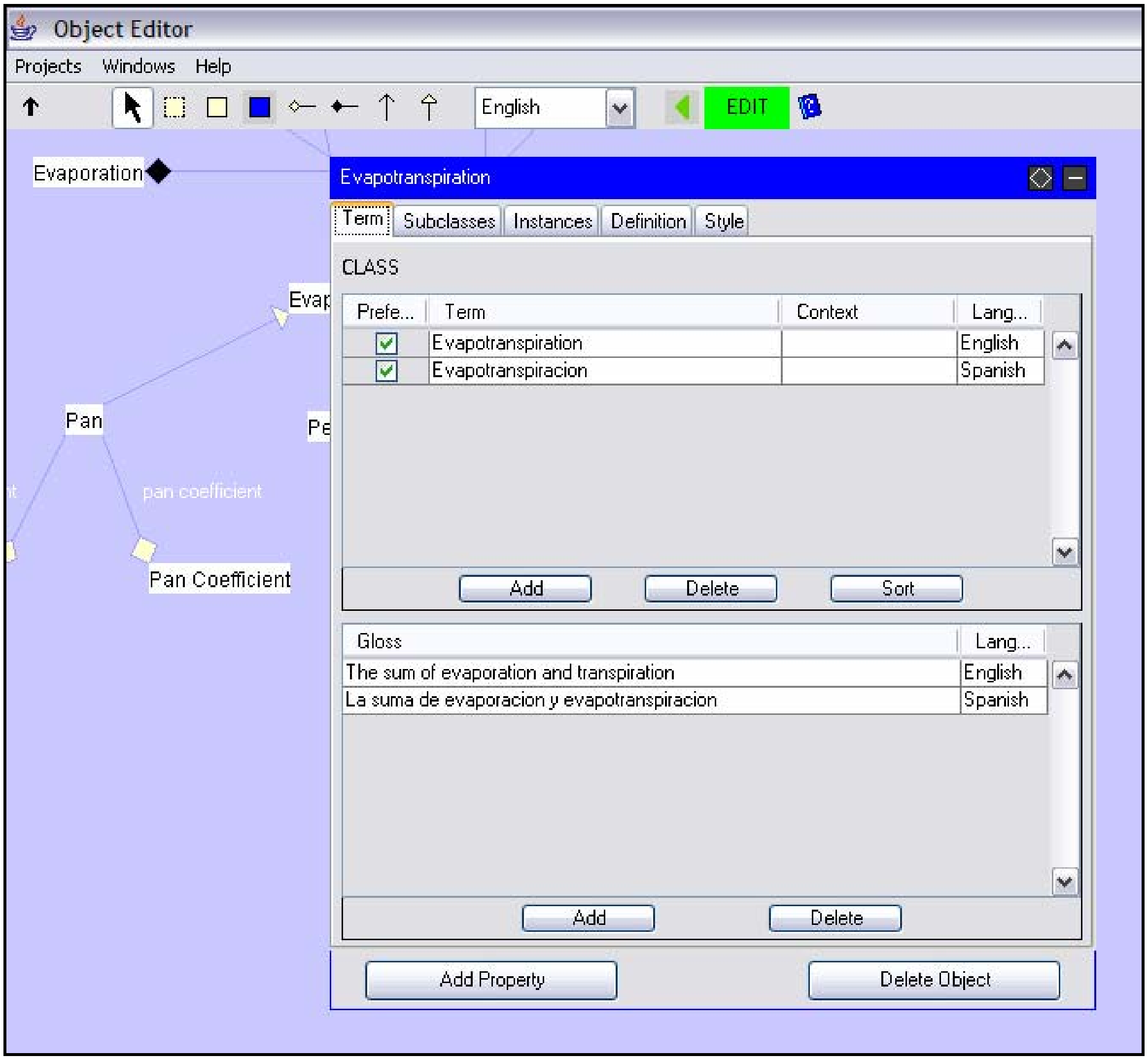


Figure 3-2. Evapotranspiration term and its gloss (short definition).

Each term (class) presented in the irrigation ontology has its definition; this ObjectEditor property allows the inclusion of a textual definition of the term in multiple languages. The terms in the irrigation ontology have definitions in English (Figure 3-3) and Spanish (Figure 3-4).

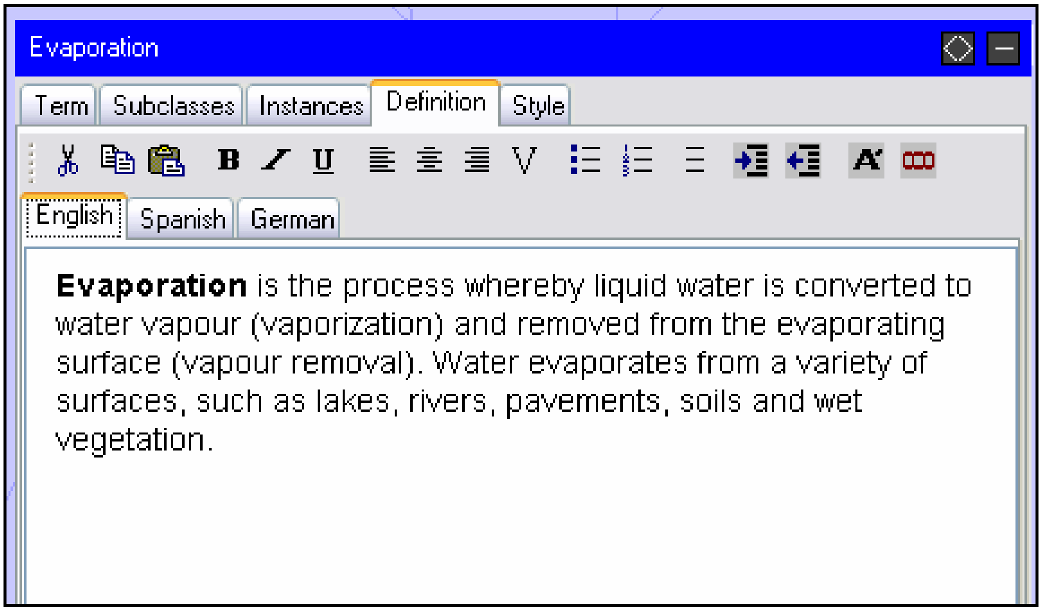


Figure 3-3. Definition of concept in English

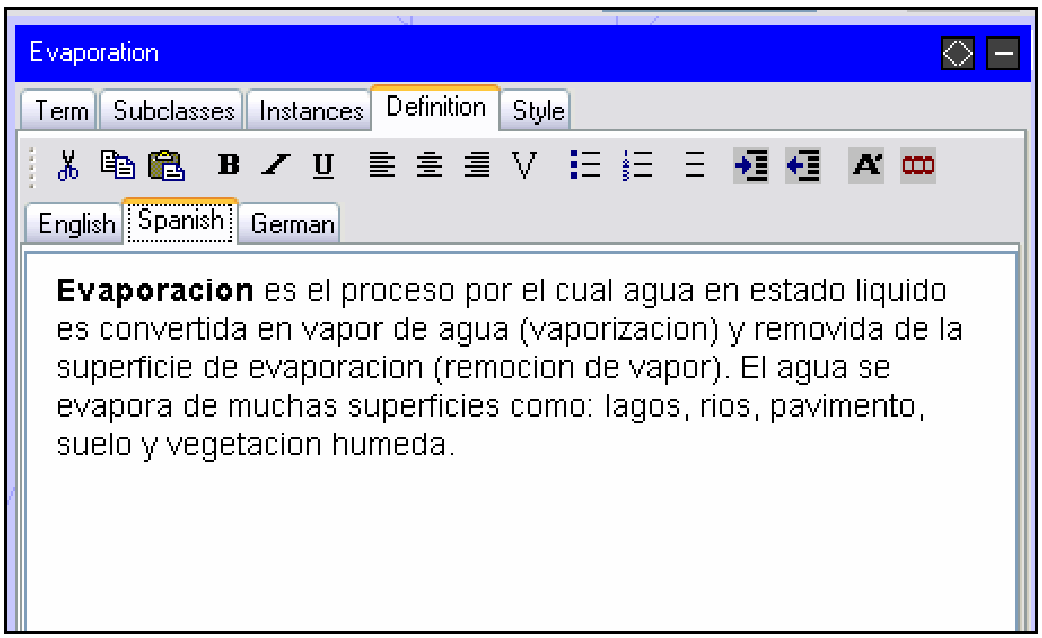


Figure 3-4. Definition of concept in Spanish

Ontology Implementation

For the irrigation ontology, the main irrigation related topics (terms) selected are: Irrigation Water Sources, Weather, Plant, Soil, Drainage, Irrigation System Design, Irrigation System Management, and Irrigation Equipment and Structures. ObjectEditor allows the creation of “modules” that permit the division of the ontology in sub areas; this permits a less cluttered, more focused presentation of the terms and relationships in the ontology. Modules are a visualization tool available in ObjectEditor; they are not a part of the ontology modeling language. The modules do not contain the same number of related terms nor do they have the same level of detail. During ontology implementation the concepts and the relationships among concepts were defined. The implementation process makes use of a top-down approach for knowledge modeling using the above defined modules as nine major irrigation and water management topics.

As defined earlier, an ontology consists of the basic terms (concepts) and relations between those terms. A domain specific terminology (set of concepts) was first assembled in a vocabulary, then that vocabulary was organized according to the objectives of the irrigation ontology (Chapter 2) and placed into nine well defined modules

Modeling process consists of identifying rules, definitions and relationships between terms and relations within a ontology. ObjectEditor has predefined rules in how to create terms and how to use relationships (Beck, 2003a). ObjectEditor provides four types of relationships: generalization, part-of, association, and sequence. Generalization is used to represent superclass/subclass relationships; a “pine tree” is a subclass of the class “tree.” Part-of is used for objects that are physically a part of larger composite objects; the class “tire” is a physical part of the class “vehicle.” Sequence is used to indicate that a concept follows another; in a sequence of classes, “socks” are worn before “shoes.” Association is used between two otherwise related concepts were none of the three previous relationship types apply. These different relationships are graphically represented in ObjectEditor by different types of vectors. The types of the relationships are identified in Figure 3-5, within dashed-line rectangles.

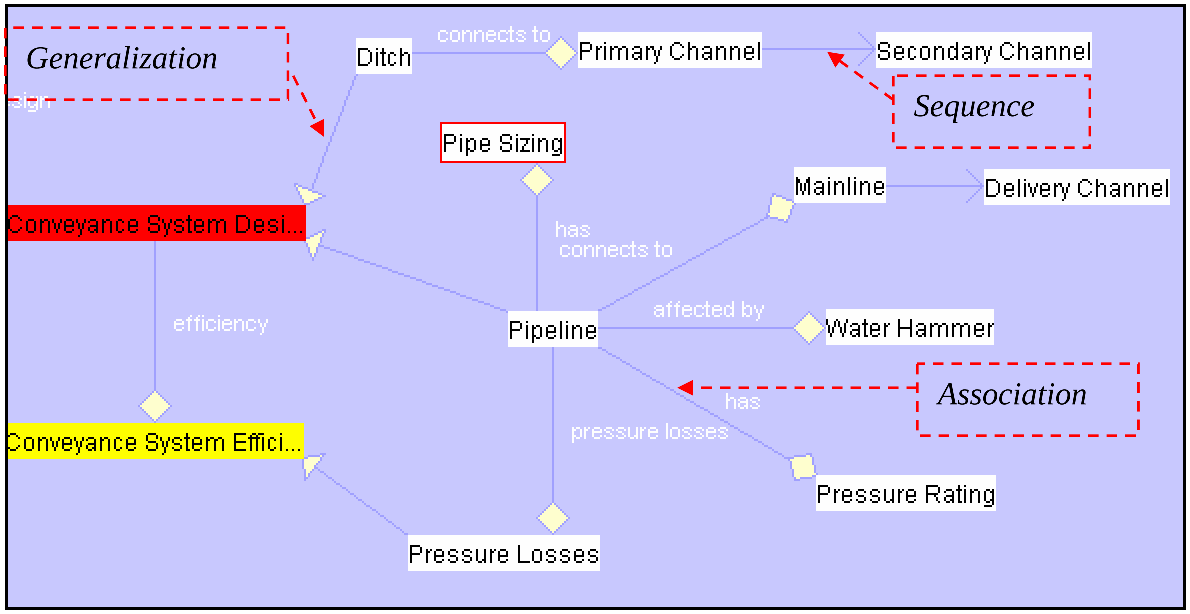


Figure 3-5. Relationships supported by ObjectEditor

The association type of relationship has association properties that can be modified by the user. An association name and a gloss have to be defined to give sense to the association (Figure 3-6). The process of defining and association relationship depends on the terms to be related. For example, it is known that a "pipeline" *has* a "pressure rating" and a "pipe sizing" (Figure 3-5). This association is defined as *has* for this type of relationships. The association name is provided to give more sense to the relation between two terms, than a general relationship could give.

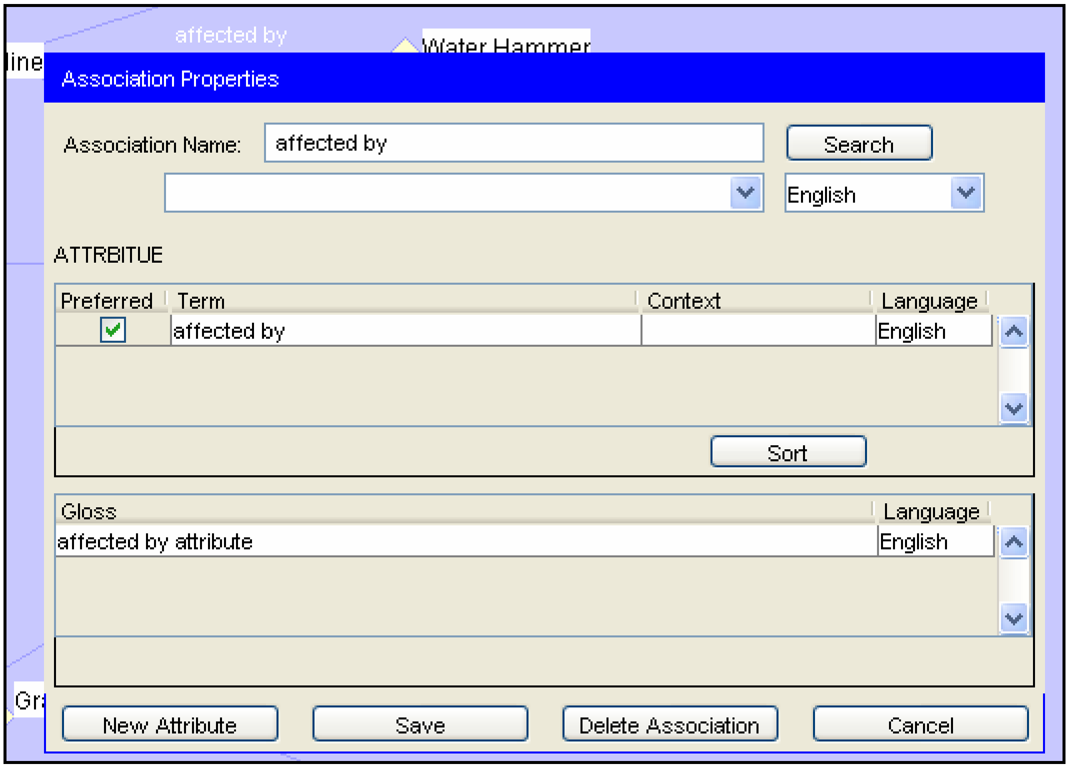


Figure 3-6. Association relationship properties

In Figure 3-7, the “part of” relationship is used for physical parts like the classes “manifold,” “lateral,” and “distribution equipment” that are parts of the class “pressurized irrigation system.” Another case represents the use of relationships of the “generalization” type; this relationship used to relate sub-classes to a more general concept or class. For example: “semi-circular,” “ridge,” and “triangular” are all sub-classes of the more general term (class) “bund;” and “bund” itself is a sub-class of “contour farming,” and so on (Figure 3-8).

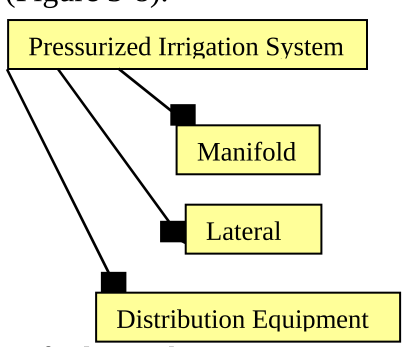


Figure 3-7. Use of part-of type of relationship

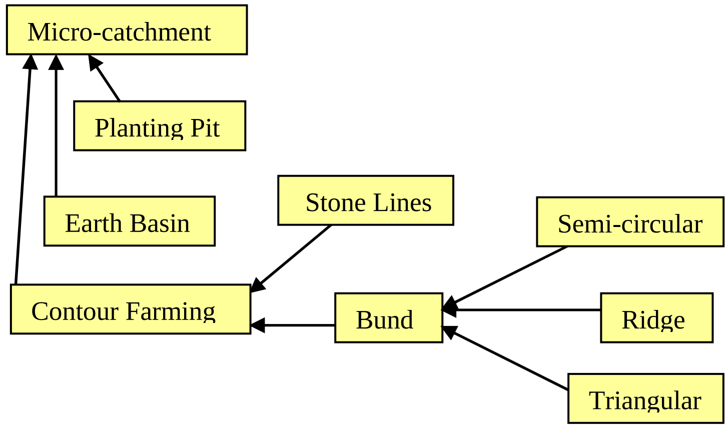


Figure 3-8. Use of generalization type of relationship

Most of the modeling issues are related to the selection of a wrong type of a relationship for the association among terms. In Figure 3-9 the "conveyance system design" with the terms surface, ground, and harvested water as parts of it are presented.

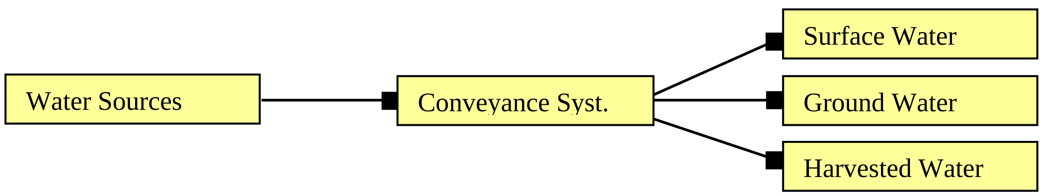


Figure 3-9. Use of generalization type of relationship

The main issue with this design is that surface, ground, and harvested water should be sub-classes of "water sources," associated through the generalization relationship with "water sources," This design is presented in Figure 3-10.

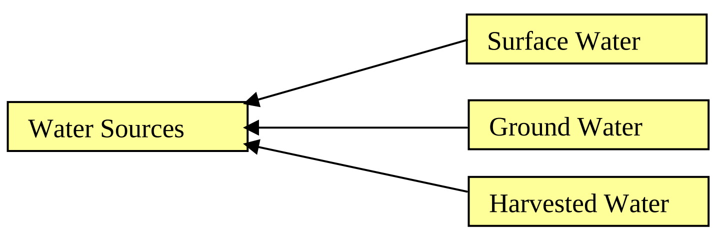


Figure 3-10. Use of generalization type of relationship

In an example of a sequence, a primary channel is followed by a secondary channel, and secondary channel by a distribution channel. In this case the particular order is important. In a real irrigation project the secondary channel can only be present after a primary channel, and a delivery channel should go after a secondary channel, and this is reflected in Figure. 3-11. Nevertheless, a delivery channel can sometimes go directly after a primary channel if the secondary channel does not exist in the particular system.

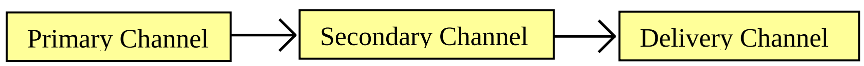


Figure 3-11. Use of the sequence relationship

Often concepts need clarification. Using the concept “precipitation” as the source of water directly available to the plant is erroneous. However “precipitation” includes rain, snow, and hail, and of these three concepts only rain is the precipitation that is directly available to the plant.

Relocation of entire groups of terms may be necessary to make an ontology more functional. As an example, originally the “irrigation system design” concept included concepts related to system selection and equipment selection. System design includes concepts like terrain conditions, soil characteristics, crop requirements, and others. All these factors will influence the choice of system and are used in the calculations involved in the irrigation system design. However, after initially including all those terms in the design it was decided that equipment selection was related to irrigation system design, but it would be better located within the irrigation equipment topic.

Following is a general description of the relevant points of each of the main topics (Figure 2-4), known as *modules* in ObjectEditor. In this ontology all the terms are defined in the context of their relation to irrigation. The “weather” module includes terms that are indirectly related to irrigation like “wind,” “radiation,” “temperature” and “precipitation.” All of them contribute to “evaporation” to which they are related via *associations.* Evaporation is also part-of “evapotranspiration” so the ontology will relate those two terms. Since the methods to calculate evapotranspiration are important to determine irrigation requirements the ontology also includes the “Pan,” “Penman-Monteith,” and “Blaney-Criddle” methods of estimating reference evapotranspiration. It is important to clarify that not all the terms related to weather are included; the irrigation ontology is not intended to include all terms in any topic, just those relevant to the limited domain of the ontology. However, ObjectEditor permits the sharing of the ontology so it can be edited and expanded as needed for other applications.

The topic “plant” includes terms related to the plant physiology and also to the water use by the plant. Basic concepts like “root,” “stem,” and “leaf” are all physical parts of the plant and are related as such. Terms related to “plant type,” and “growth season” are also included since those concepts are related to “transpiration” and “evapotranspiration” that are used to estimate “water requirement” terms that are also included in this module. The two examples presented above show how the topics “weather” and “plant” are related thru the term “evapotranspiration” demonstrating that all the ontology is interconnected.

The “soil” module is formed by five main groups of terms, “soil available water,” “soil chemistry,” “structure,” “texture,” and “topography.” One example is presented in Figure 3-12, where “texture” is associated by the content of “clay,” “sand,” and “silt,” and “loam” is the combination of specific proportions of those materials.

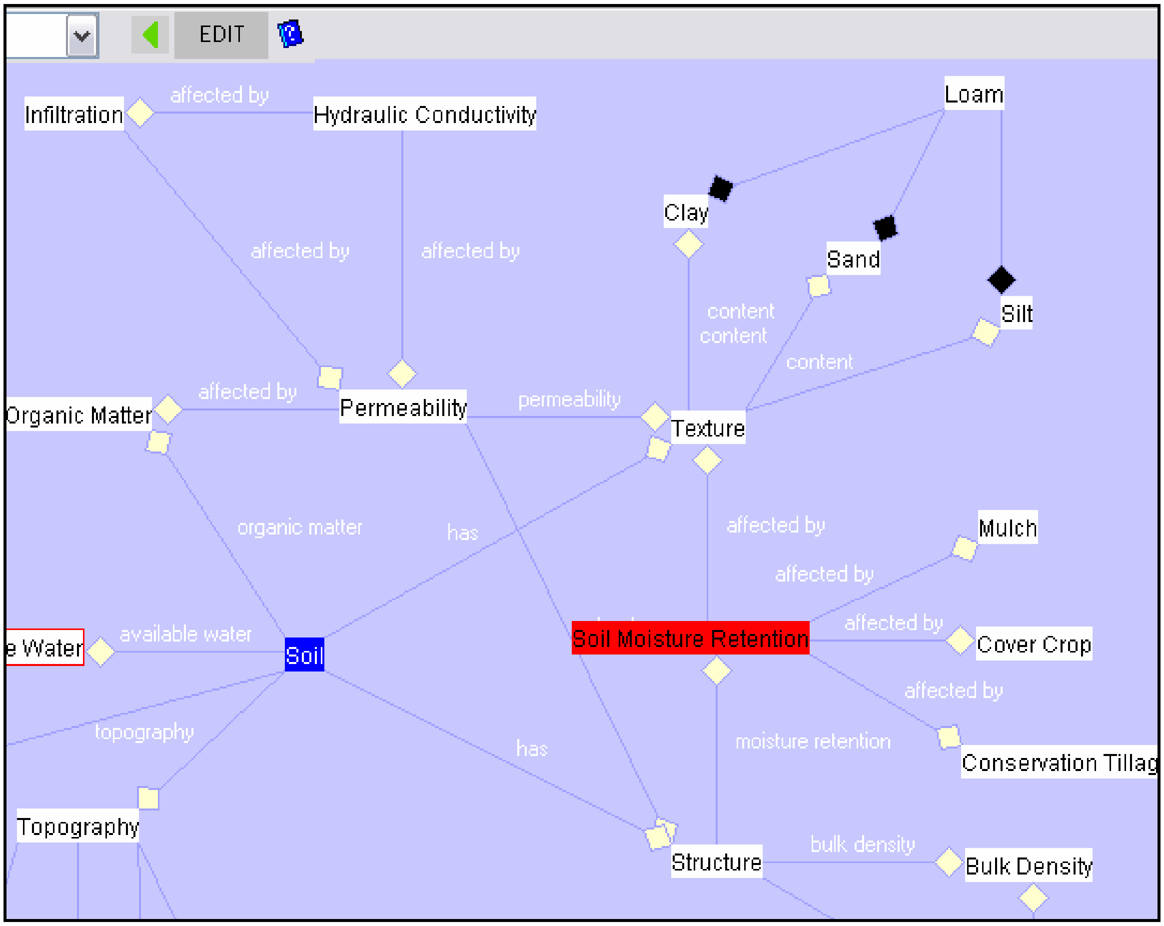


Figure 3-12. Sample of the soil module

Other section of the same figure shows the term “soil moisture retention” and how it depends on “mulch,” “cover crop,” and “conservation tillage,” practices that affect the soil capacity of retaining moisture. It does not appear on the figure but “soil moisture retention” is also related to “texture” and “structure.”

The “water sources” module includes the main sources of water used for irrigation. Those sources include “surface water,” “ground water,” and “harvested water;” all of them receive some water from “precipitation” then they are *associated* to it. Another source in this module is “reclaimed water” (Figure 3-13).

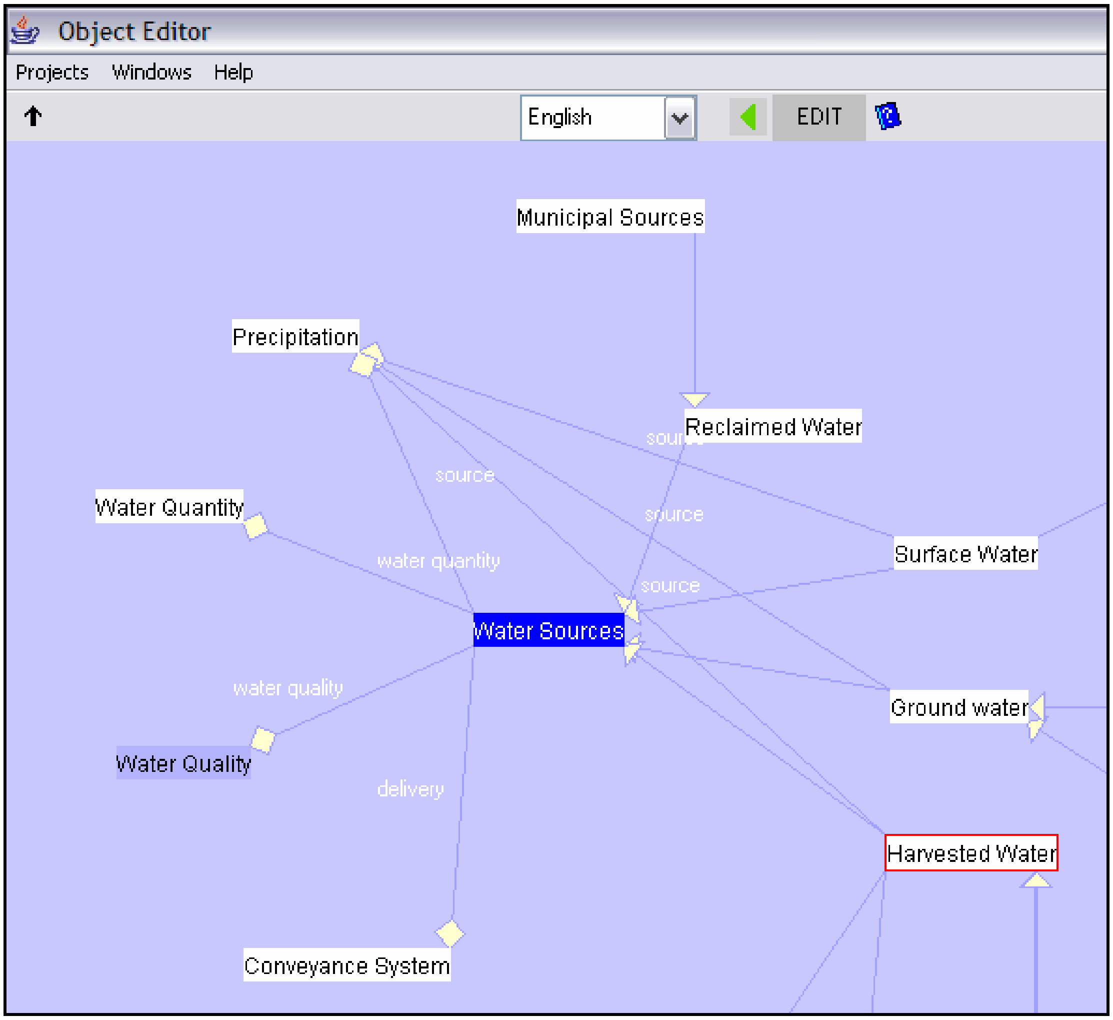


Figure 3-13. Sample of the water sources module

Also related to “water sources” but not subclasses of it are “water quality” and “water quantity.” Water quality is a smaller module that includes terms like “water hardness,” “electrical conductivity,” “pH,” and “total dissolved solids.”

Under the “drainage” topic the terms include “drainage considerations,” “drainage clogging” and “drainage design;” the design includes various sub-classes like “tile drainage” and “ditches.” All of these sub-classes are related with “drainage” via the *generalization* relationship (Figure 3-14).

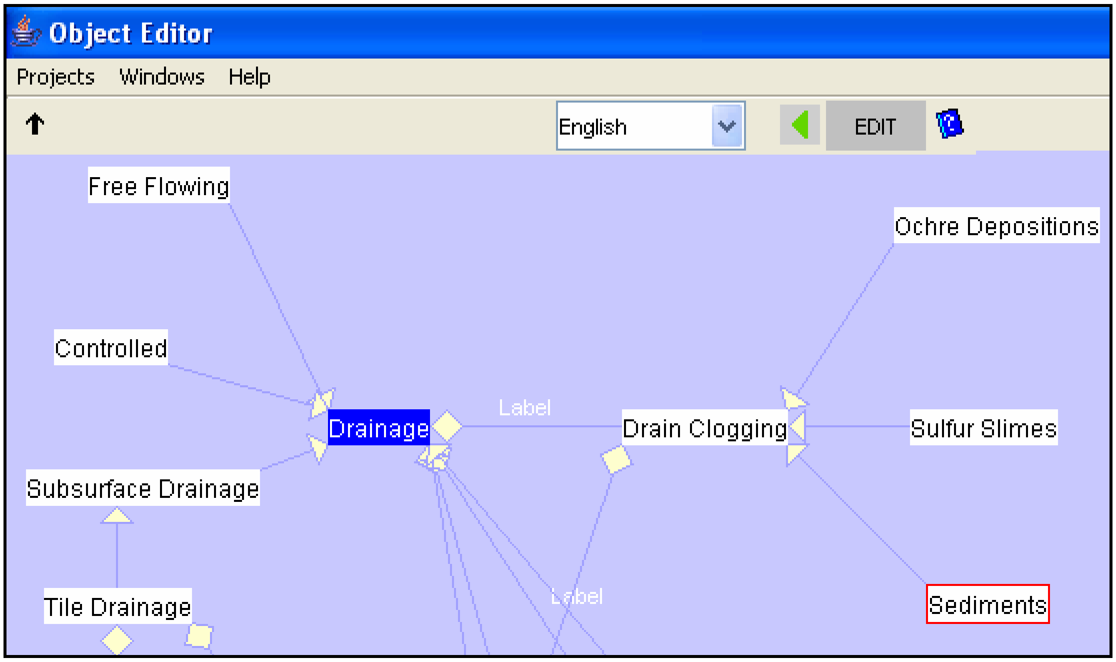


Figure 3-14. Drainage module, sub-classes with *generalization* relationships

The “system design” module is the most complex of all the modules included in the ontology. It has more than 50 terms and around 60 relationships. A view of a small selection of this module is show in Figure 3-15. This module is related to most of the other modules like “weather,” “plant,” “soil,” “irrigation equipment and structures,” and irrigation system management.” Some of the relationships and examples of complexities of this module are presented below.

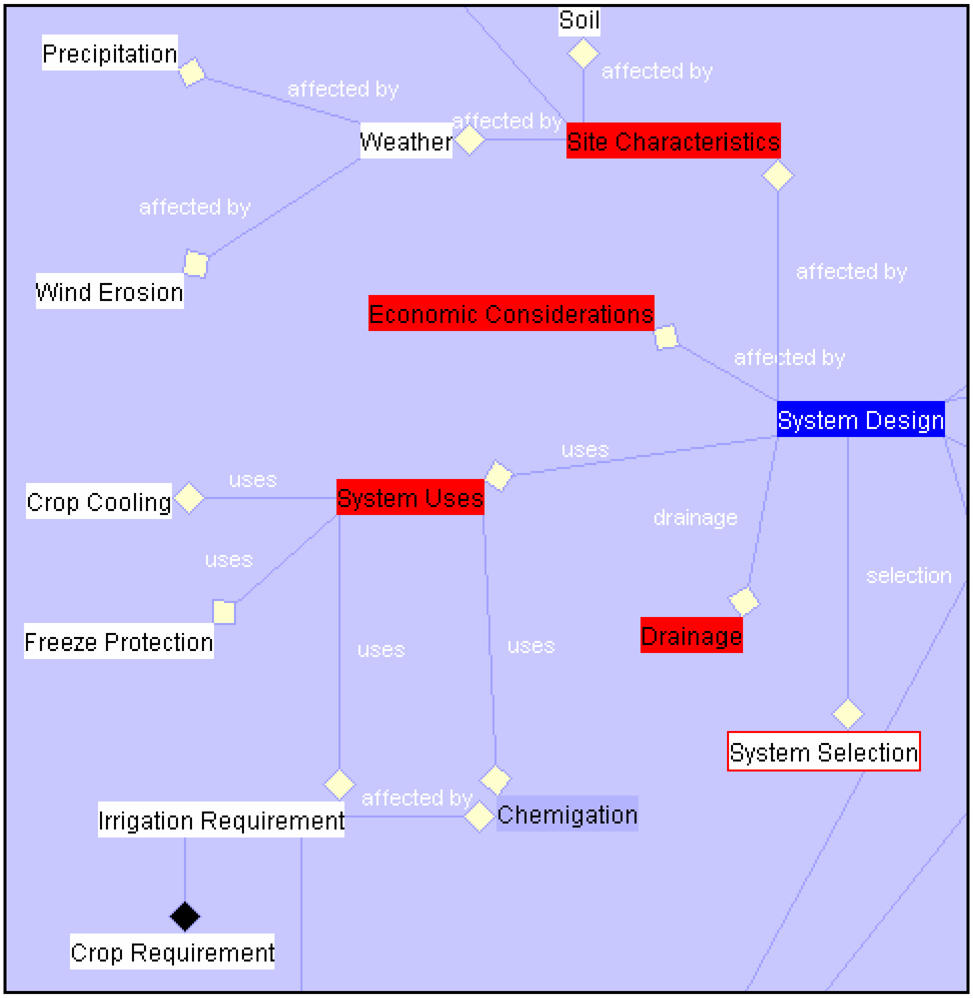


Figure 3-15. A small section of the system design module

System design is related to the soil module through "soil characteristics," and to the "plant" module via "irrigation requirement" and "crop requirement." Relations of the system design with some other modules (topics) are presented below in Figure 3-16. Irrigation system layout relates to the "plant" module through the terms "planting system," and "spacing." Pumping system design is associated with "irrigation equipment and structures" by way of "pumping equipment." Similarly, "conveyance system design" and "pipeline." Pumping, "conveyance," and "distribution efficiencies" have also relationships with terms in the "irrigation system management" module.

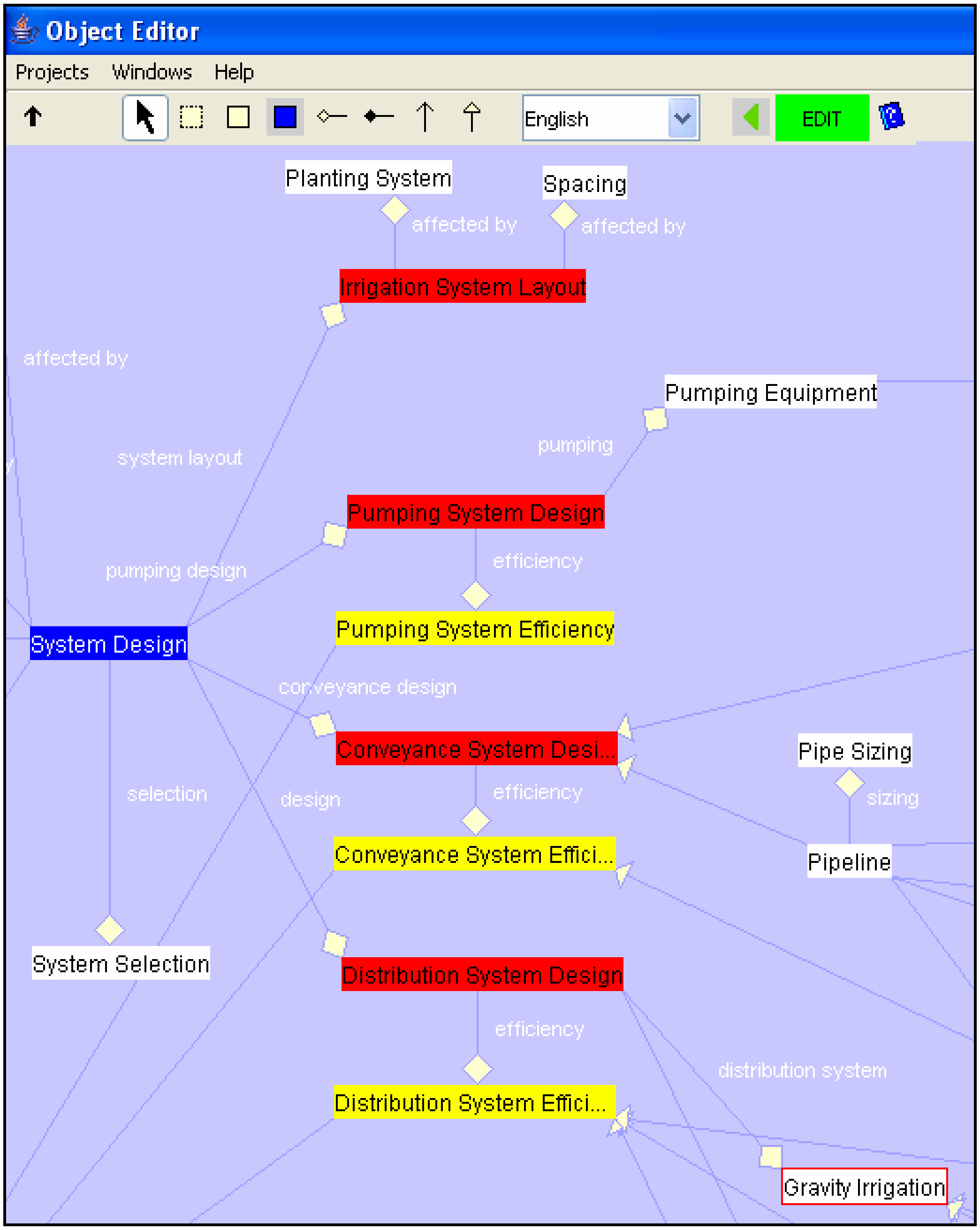


Figure 3-16. A section of the system design module

The next module comprises “irrigation system management” which is related to “irrigation scheduling,” “irrigation system maintenance,” and “chemigation.” Irrigation system maintenance includes topics like “pump check,” “pressurized irrigation,” and “surface irrigation” (Figure 3-17). The ontology aims at containing some of the practices that a farmer should follow to maintain an irrigation system. For example “pressurized irrigation" includes "check lines for leaks," "clean lines or pipes," "clean filters," "irrigation system calibration," and "uniformity test."

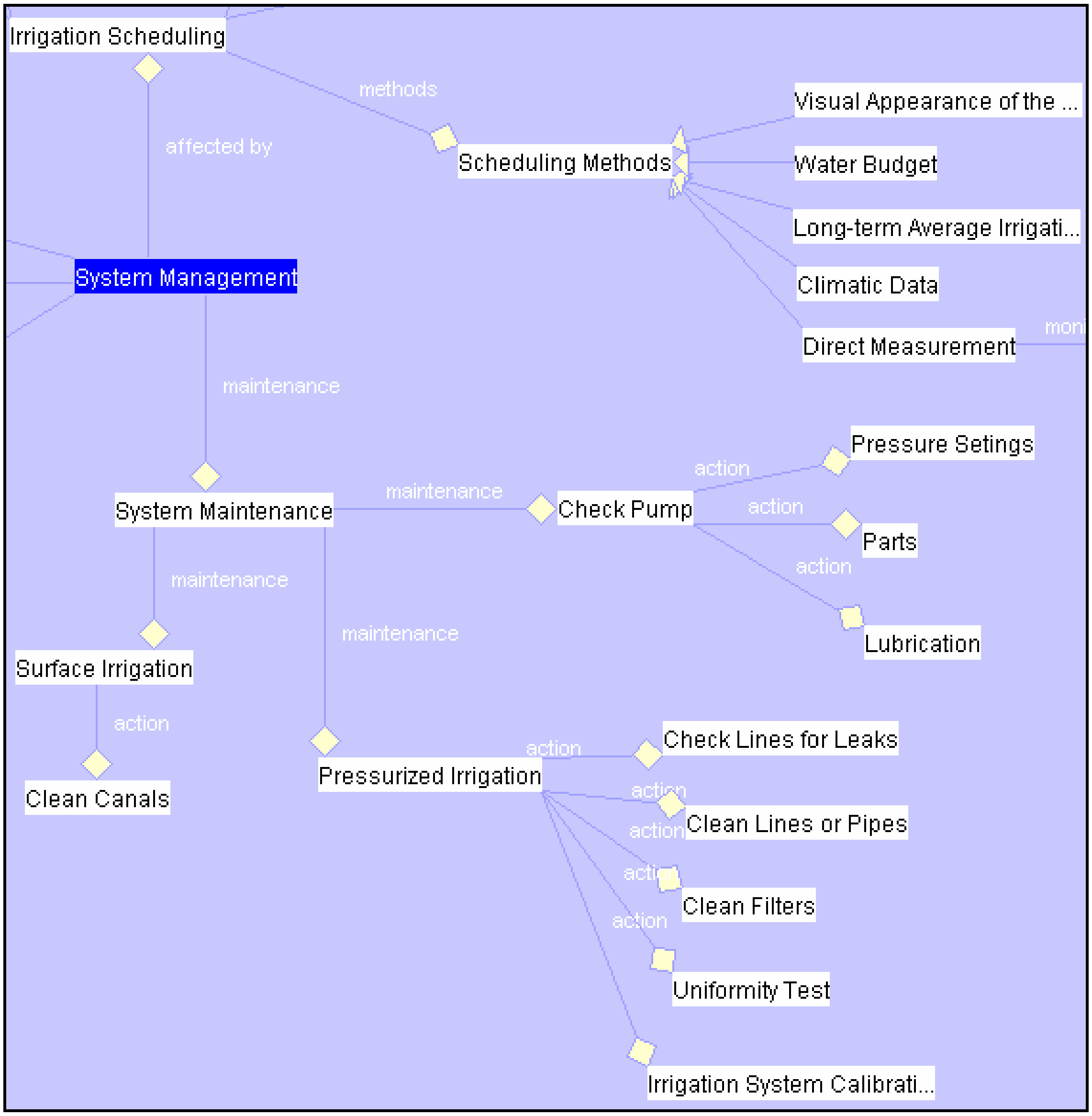


Figure 3-17. Partial view of the irrigation system management module

The last module presented in Figure 3-18, is the "irrigation equipment and structures" with the following sub-classes: "system control," "filtration equipment," "conveyance equipment," "pumping equipment," "distribution equipment," "system controllers," and "chemigation equipment." The difference between "system control" and "system controllers" is that the first refers to equipment like "valve," "flow meter," "pressure regulator"; and the second refers to sensors and automatic controllers.

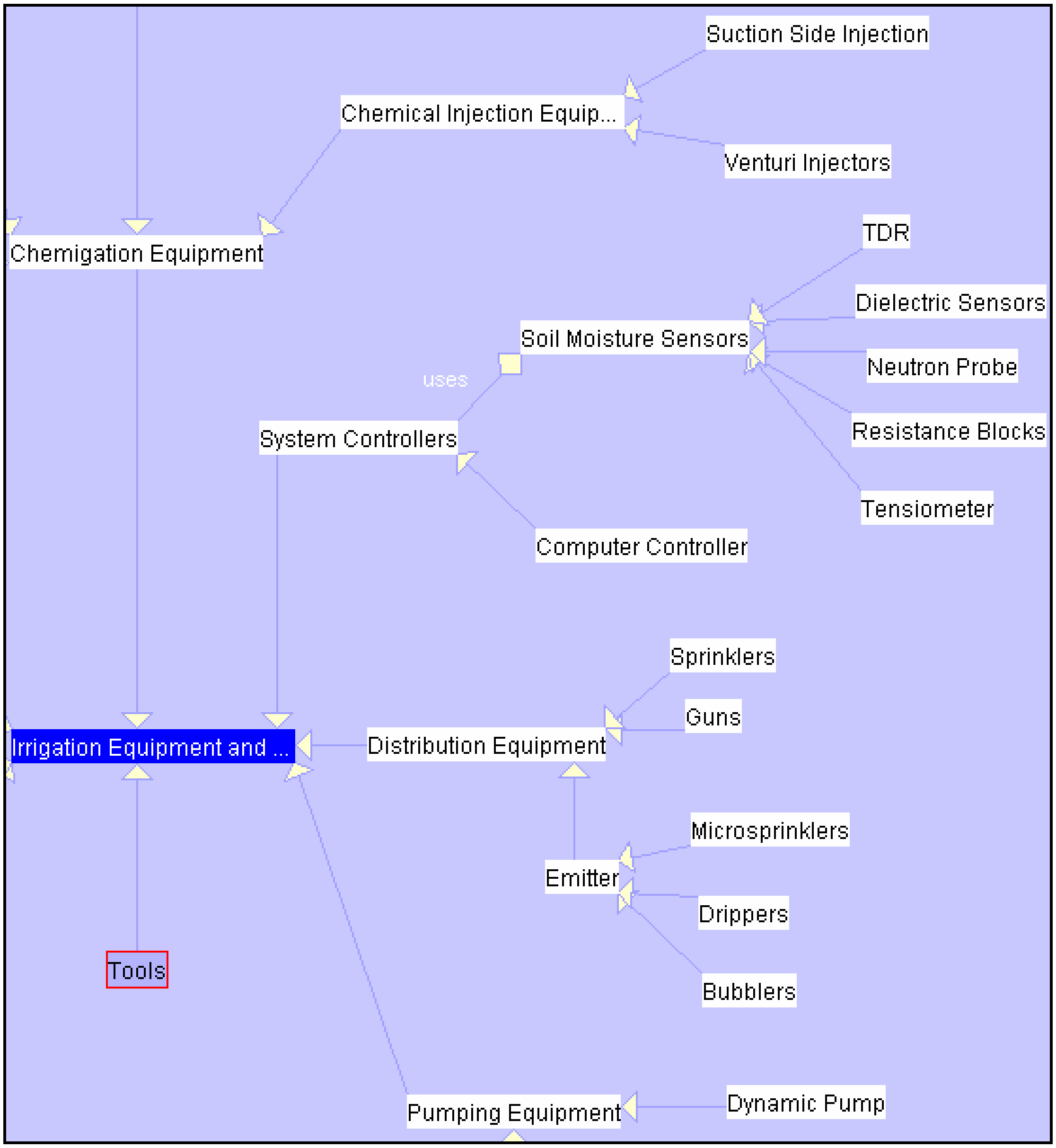


Figure 3-18. A section of the irrigation equipment and structures module

Conclusions

The implementation of the ontology is what allows the presentation and sharing of the knowledge modeled and contained in the irrigation ontology. In order to create a common irrigation ontology, a logical framework and classification of terms was developed with the help of experts in the domain. The terms included in the ontology are clear and with definitions that are easy to understand. The resulting irrigation ontology includes formal definition of concepts and, when need the relationships are also defined. A structured and reusable vocabulary was developed for the irrigation ontology.

Building ontologies manually requires a lot of time, especially during the conceptualization and implementation processes. The modeling process can be complicated and may be difficult to reach consensus in some of the terms, their definition and relationships. At this time the Irrigation Ontology consists of more than 270 terms, and around 300 relationships among those terms (Appendix A). Future work should include the development or incorporation of an automated implementation process in order to work with larger datasets.

CHAPTER 4
EDUCATIVE ILLUSTRATIONS

Introduction

In many rural development programs in Latin America and Africa, field-level training for small farmers is the most appropriate means of communicating new ideas and practices. In many rural areas poverty and illiteracy are common and people cannot use training materials containing only textual information and even graphical information may not be understood if it is too technical or abstract. Printed educational materials are important since people could use them to reinforce the concepts and remember what they have learned. However, staff responsible for conducting the training often have few resources to help them with the process. Appropriate resources usually have not been developed to fit the conditions of a particular audience.

More work is needed in the development of applications that could facilitate the production of personalized training materials as a way to transmit information. This project is a response to this problem as it aims at development of an application to produce appropriate training manuals for non-literate users. The focus of the project is on Africa and Latin America, which contain a number of countries with a high rate of illiteracy.

This project uses an ontology based system that is designed for storing content, which includes concepts, media such as text, and images (i.e., pictures, drawings, and diagrams) and can also include animations, sounds, and video. There are many advantages in utilizing an ontology system for storing educational resources. Immediate advantages are that educational materials can be more easily produced compared with conventional tools (e.g., PowerPoint®, PDF®, and Flash®). Information can be shared and reused in ways that are not possible using conventional tools due to proprietary restrictions. For example, conventional software is not designed to retrieve content from a database. This means that if something changes in the content, then, the presentation has to be changed manually. Flash® permits linking to artwork stored in a database. However, Flash is a proprietary language that does not allow easy manipulation of the file that composes the graphic; instead a new graphic has to be developed to include each desired variation. There is also a need for low cost development tools and the possibility of cooperative work that can be done by working with an online tool. These are just some of the reasons why a new system to produce illustration based educational materials is needed. The use of an ontology will facilitate the updating of information in various formats and different localized presentations (e.g., print, Web-based) can be created automatically from the same content.

This work presents an approach for managing information and producing localized educational materials by using an ontology system to manage content. It is applied to irrigation and water management information topics and produces illustration (drawing) based training materials for non-literate farmers.

Graphical Communication

Systems of communication based on graphics have been successfully employed (e.g., Chinese, Egyptian, Mayan) (Yazdani and Barker, 2000). Nevertheless, to convey information thru graphics, they have to be simple enough to be easily understood by people with low educational levels, and at the same time those graphics have to transmit complex information. Line drawings are a good tool to produce simple graphics.

However, to convey complex information just relevant information has to be included in the drawing, avoiding the inclusion of unnecessary details. The graphics have to also be relevant for the conditions of the people that are going to use them.

Development of educational materials that are culturally sensitive is called localization. *Localization* is the process of targeting a product to a local clientele by "translating" the product and adding local, specific features where applicable (Luong et al., 1995). In the case of illustration based educational materials, these have to be developed in such a way that the clientele using them can associate themselves with the actions being presented in the manual's drawings (e.g., race, gender, tools, environment, etc).

In this project, culture is considered as the collectively held set of attributes (e.g., values, believes and basic assumptions) and behaviors, which is dynamic and changing over time. Culture affects many elements of communication such as, language, colors, graphics, icons, date, time, numbers, currencies, units, and personal titles (Dahl, 2003). In other words, culture affects the way people perceive things, and knowledge.

When an educational manual has to be produced for multiple audiences, for example, in Africa, Latin America, and Asia, the conventional approach results in duplication of efforts and poses the challenge of producing and updating the information in different formats that are concordant to the individual realities of each culture.

The inclusion of localization is focused at improving communication among facilitators and learners. Communication is the transfer of a message from one person to another, so that it is understood, and hopefully, so that it invokes a response (Figure 4-1). There is always a sender and a receiver in any communication. At least there is an intended receiver. Sender and receiver have different personal and cultural realities. The use of localization should increase the success of a message being transmitted among parties.

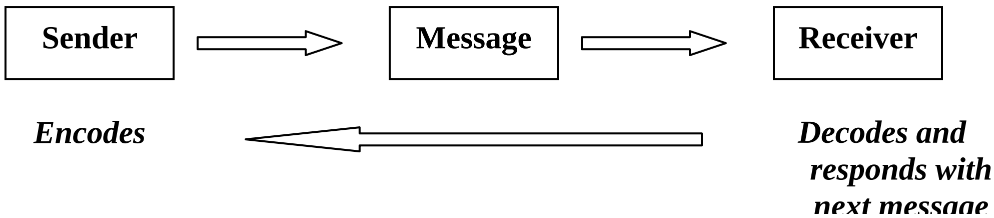


Figure 4-1. Communication model adapted from Funch (1995)

Senders and receivers each have their own reality formed by their experiences, their perceptions, their ideas, etc. (Funch, 1995). Due to this background they will perceive, experience, and interpret things differently. Each individual will always perceive the same event a little different. The message in western societies is often verbal, something that is being expressed in language, spoken or written. But there is also a non-verbal portion, covering everything else, most notably body language that is represented thru images. Nevertheless, in any communication process it cannot be granted that the receiver will interpret the message the same way as the sender intended it. In the usual communication process among people, many factors have an effect on the message, influencing what the receiver perceives from the sender (Figure 4-2).

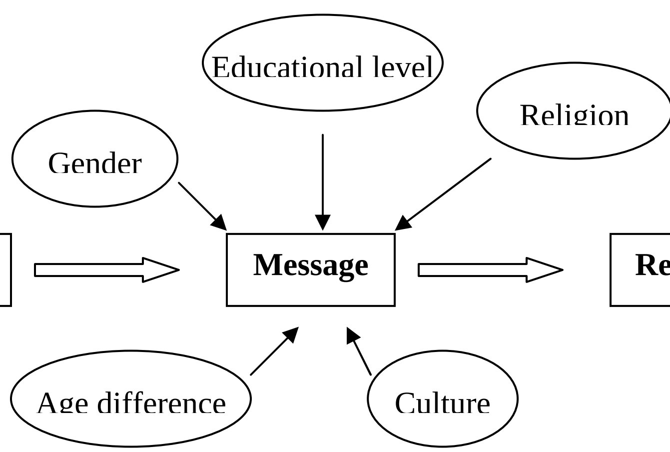


Figure 4-2. Interferences on the communication model modified from Funch 1995. When cultural differences are included in the communication process, this becomes more complex. Language complications and cultural differences affect the transmission and interpretation of a message. The inclusion of localization in the development of educational materials should help reducing miscommunication issues. To have an efficient intercultural communication process, cultural sensitive materials could be used to avoid prejudices and to facilitate the adoption of local cultural characteristics into the communication process.

Educational Materials

Once the topic of the training relevant to the community has been identified, localized educational materials can be developed. To accomplish this, characteristics of the population have to be considered. It is possible to use some of the information provided by the local extension agents or trainers, but more often data has to be collected through questionnaires and interviews (see future work as described in the conclusion section below). Then this information is incorporated in the design of the educational manuals.

Experiments with Vectorizing Images, Options for Creating Vector Graphics

Various techniques were tested to convert digital pictures to line (vector) drawings in order to represent them using vector graphics. A vectorization tool that replaces pixels patterns with vectors from Flash® (Flash, 2004) provided some good visual results (Figure 4-3), still, the resulting drawings were too complex (too many colors, and vectors) to be easily changed as required for this project. Furthermore, the vectorization tool only performed well on simple, well-defined patterns.

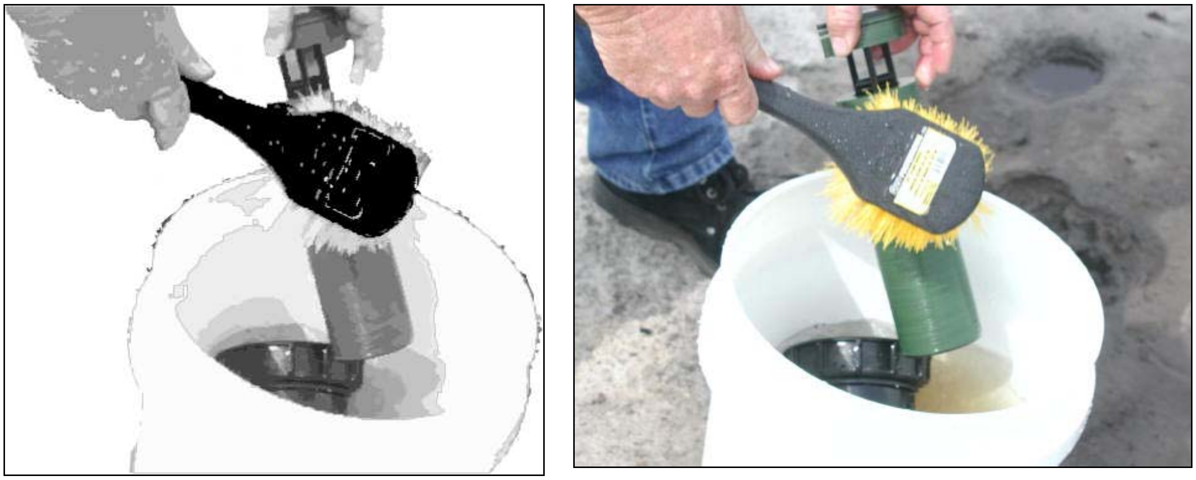


Figure 4-3. Vectorization using Flash® and original digital picture

Another technique was to use pattern recognition software, to extract the main features from a digital picture. The software used was GIMP© (GIMP, 2004), and results are presented in Figure 4-4. The complication was that to have a fairly clear pattern, the background of the picture needed to be a plain color, and without shadows.

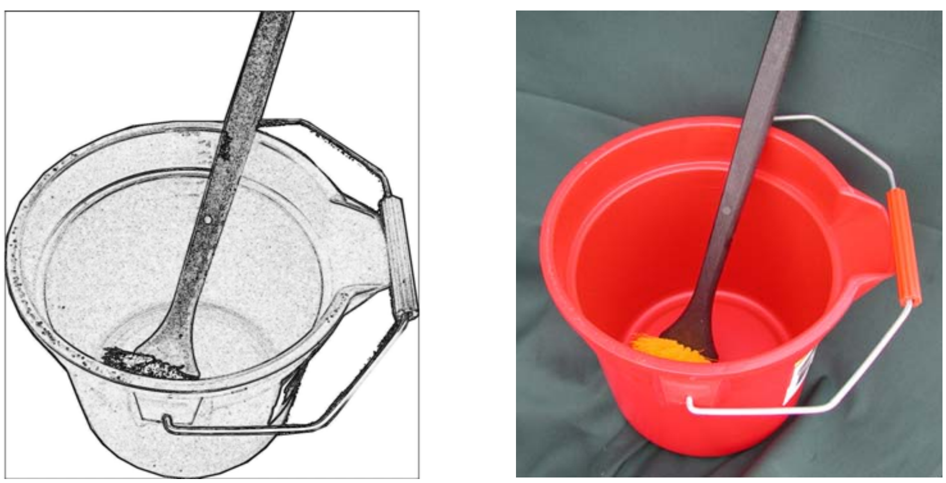


Figure 4-4. Pattern recognition using GIMP© and original digital picture

The use of Flash® and GIMP® to transform digital pictures to vectors was very time consuming, due to the time needed to edit the pictures manually, plus the processing time required by the software. The process also required high quality photographs, without any objects in the background. Even the cloth used as a background in Figure 4-4 caused problems with the vectorization process.

Scalable Vector Graphics

In order to handle localization of drawings, scalable vector graphics (SVG) format has to be utilized. SVG format was developed by the World Wide Web Consortium (SVG Working Group, 2004; W3C, 2004a). It handles vector graphic display and animation based on the extensible markup language (XML Working Group, 2004). It is a text-based language that is resolution independent. Localization applied to scalable vector graphics means that imagery and text can be easily converted to different languages and cultural settings. Changing just one XML tag can modify graphics to adhere to local needs. This means that if the color of the skin has to be changed, just the portion of code that affects the skin color has to be modified. This can be done automatically by linking the SVG graphics to the object database thru the data-handling feature in SVG that can be used to create dynamic graphics. In the SVG sample code below, notice that only one part of the code (in bold and marked with an arrow) needs to be changed in order to alter the color of the skin. This method can be used to modify some features of the graphics. When other characters need to be added (i.e. cloths, tools) those can be switch on and off using the SWITCH tag available in the SVG code.

SVG Sample code:

```
<?xml version="1.0" encoding="utf-8"?>
<!-- Generator: Adobe Illustrator 11.0, SVG Export Plug-In . SVG Version: 6.0.0
Build 78)  -->
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.0//EN"
"http://www.w3.org/TR/2001/REC-SVG-20010904/DTD/svg10.dtd" [
	<!ENTITY ns_flows "http://ns.adobe.com/Flows/1.0/">
	<!ENTITY ns_extend "http://ns.adobe.com/Extensibility/1.0/">
	<!ENTITY ns_ai "http://ns.adobe.com/AdobeIllustrator/10.0/">
	<!ENTITY ns_graphs "http://ns.adobe.com/Graphs/1.0/">
```

```
<!ENTITY ns_vars "http://ns.adobe.com/Variables/1.0/">
<!ENTITY ns_imrep "http://ns.adobe.com/ImageReplacement/1.0/">
<!ENTITY ns_sfw "http://ns.adobe.com/SaveForWeb/1.0/">
<!ENTITY ns_custom
"http://ns.adobe.com/GenericCustomNamespace/1.0/">
<!ENTITY ns_adobe_xpath "http://ns.adobe.com/XPath/1.0/">
<!ENTITY ns_svg "http://www.w3.org/2000/svg">
<!ENTITY ns_xlink "http://www.w3.org/1999/xlink">
<!ENTITY st0 "fill:none;stroke:#50470D;stroke-width:0.25;">
<!ENTITY st1 "fill:none;stroke:#A6B05E;stroke-width:0.25;">
<!ENTITY st2 "fill:none;stroke:#325C3C;">
<!ENTITY st3 "fill:#ED5100;">
<!ENTITY st4 "fill:#50470D;">
<!ENTITY st5 "fill:none;stroke:#FF6309;stroke-width:0.25;">
<!ENTITY st6 "fill:none;stroke:#73A79F;">
<!ENTITY st7 "fill:none;stroke:#73A79F;stroke-width:0.25;">
<!ENTITY st8 "fill:none;stroke:#C6E1D8;stroke-width:0.5;">
<!ENTITY st9 "fill:#C6E1D8;">
<!ENTITY st10 "fill:#FF6309;">
<!ENTITY st11 "fill:#FFFFFF;">
<!ENTITY st12 "fill:#325C3C;">
<!ENTITY st13 "fill:#6C9A76;">
<!ENTITY st14 "fill:#73A79F;">
<!ENTITY st15 "fill:#A6B05E;">
<!ENTITY st16 "fill:#DAD9AD;">   (represents the skin color: arms and
face)
<!ENTITY st17 "fill:#DCEDE5;">
]>
<svg
```

In figure 4-5, an example of the basic use of SVG internationalization is presented. The sample code (SVG) presented above was modified in order to change the color of the skin and hair, without the necessity of altering any other components of the code or graphic.

Figure 4-5. Sample of localization with Scalable Vector Graphics (SVG)

In Figure 4-6 a new item has been added to the original drawing without the necessity of modifying the existing one. The desired feature is just switched on or off depending on what is needed for the manual.

Figure 4-6. Sample of localization with Scalable Vector Graphics (SVG)

An example of a specific task, such as cleaning of an inline filter in the irrigation system, was selected to demonstrate the process of transferring the information into a graphical form that can be used in a manual. A module showing the flow of the steps needed to complete the activity for which the training is conducted was produced. Photographs were used to represent each step (Figure 4-7).

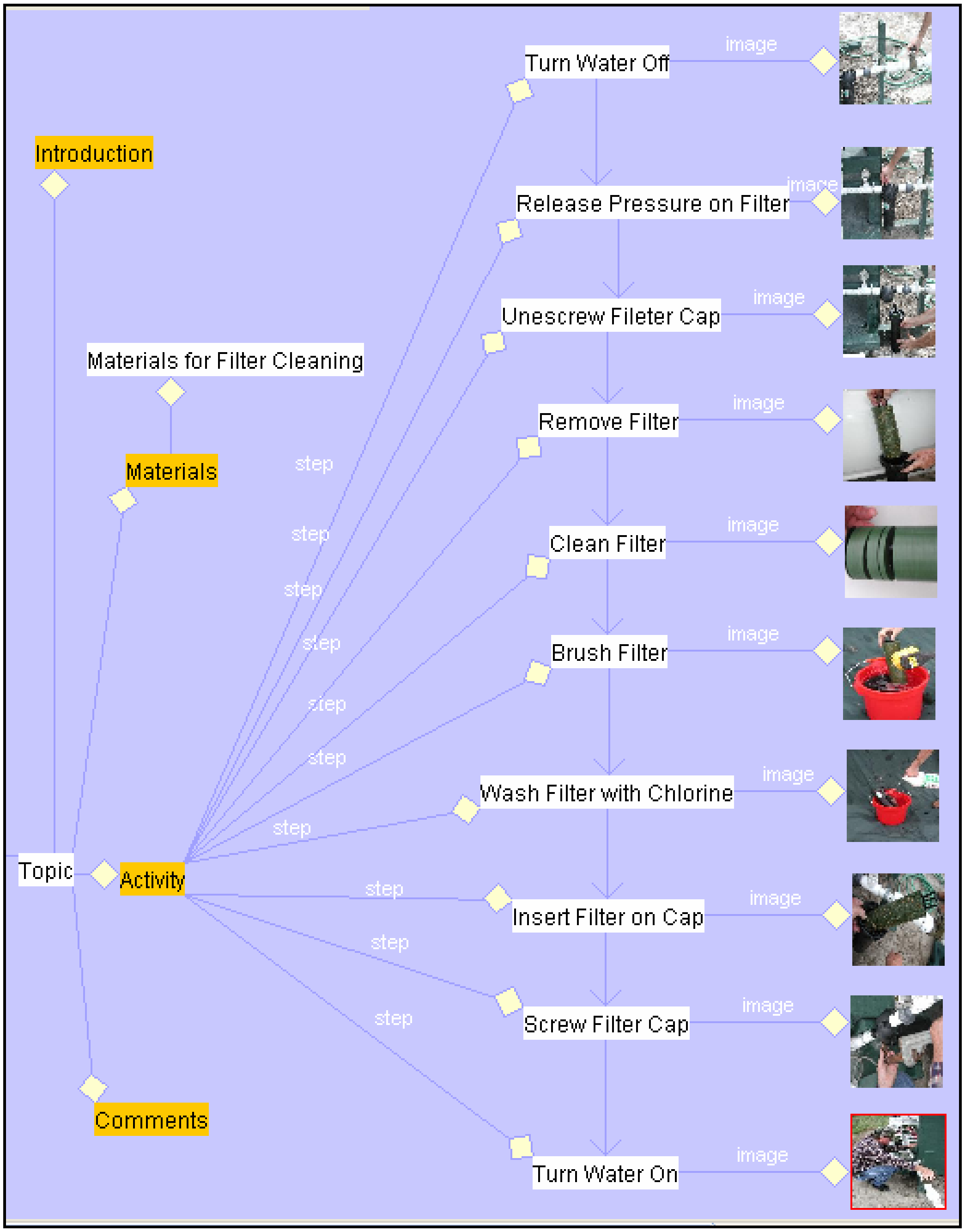


Figure 4-7. Module "Cleaning Irrigation Filters" from Object Editor

These photographs were treated as the content to be utilized by the ObjectEditor. All the components (represented by photographs) of the process being demonstrated are linked depending on the relationship among them. These linkages determine the order in which the images have to appear in the final printed manual in order to transmit the activity in a logical way. At a later stage in this project, drawings will be available as well as photographs to describe the different training activities.

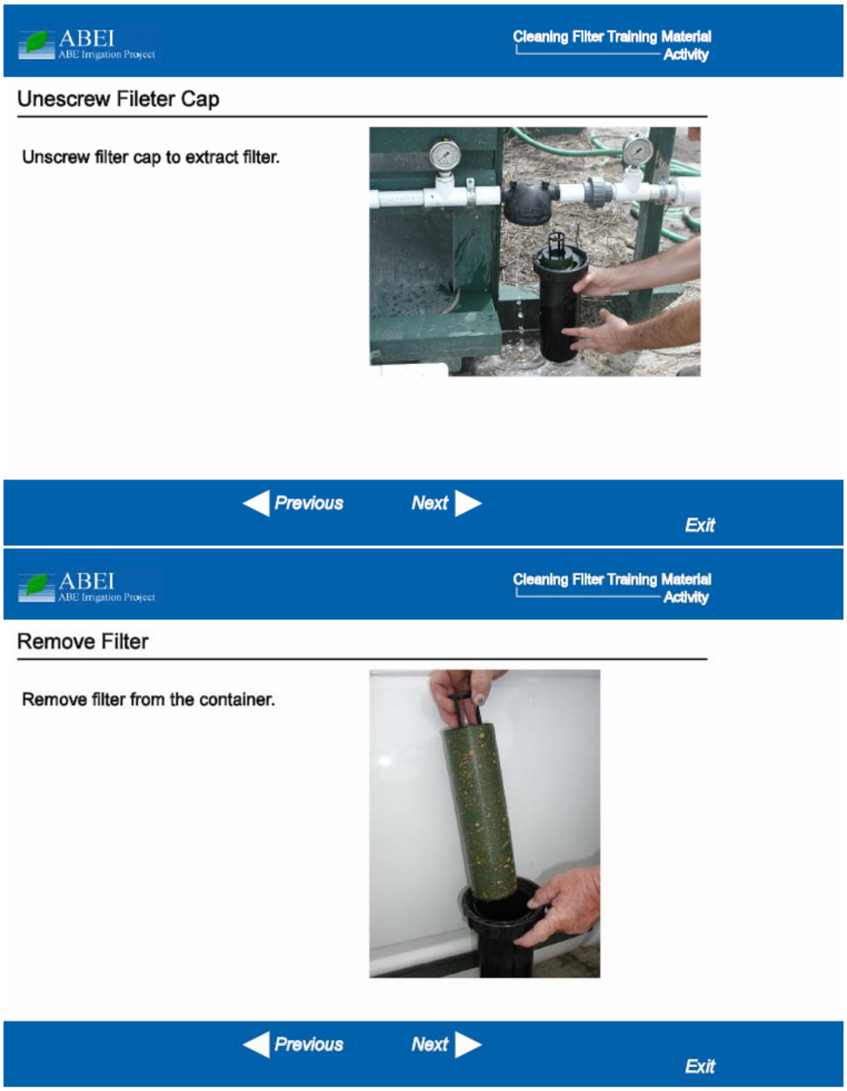


Figure 4-8. SVG presentation “Cleaning Irrigation Filters” in English

The next step was to extract the information contained in the ontology to create presentation based on SVG technology that can be seen in any internet browser capable of opening SVG files. What the SVG render does is to navigate and select the different components of the educational material like introduction, materials, activity, and comments; then it arranges them in a predefined format created also with SVGs. An example of parts of the presentation in English and Spanish is presented in Figures 4-8 and 4-9 respectively.

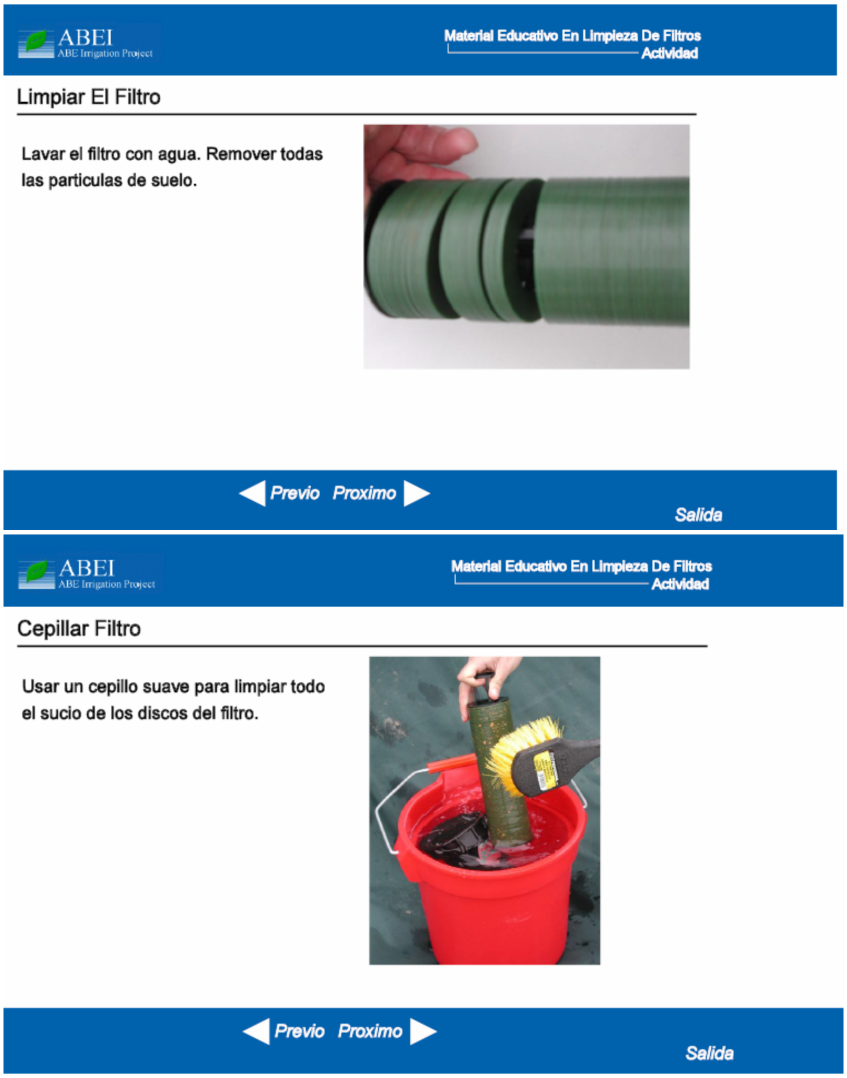


Figure 4-9. SVG presentation “Cleaning Irrigation Filters” in Spanish

GraphicsEditor

GraphicsEditor is a tool incorporated into ObjectEditor that permits the creation of objects that have vector graphics as content. This tool facilitates the combination of the graphic’s properties with the properties of the objects they help represent. GraphicsEditor was used to create the graphics for the objects to be used in the educational materials.

This application allows the creation of vector graphics based on the scalable vector graphics (SVG) standard by the World Wide Web Consortium.

GraphicsEditor allows the creation of graphics using lines and polygons. When a graphic is completed all its parts (e.g., lines and polygons) can be selected to form a group. Group is a function of GraphicsEditor that gives the possibility of adding properties to the graphic. An example will be used to explain this process. The first step was the creation in the irrigation ontology of the instance called Maize (Figure 4-10) this instance is a subclass of the Monocot class under the term plant classification.

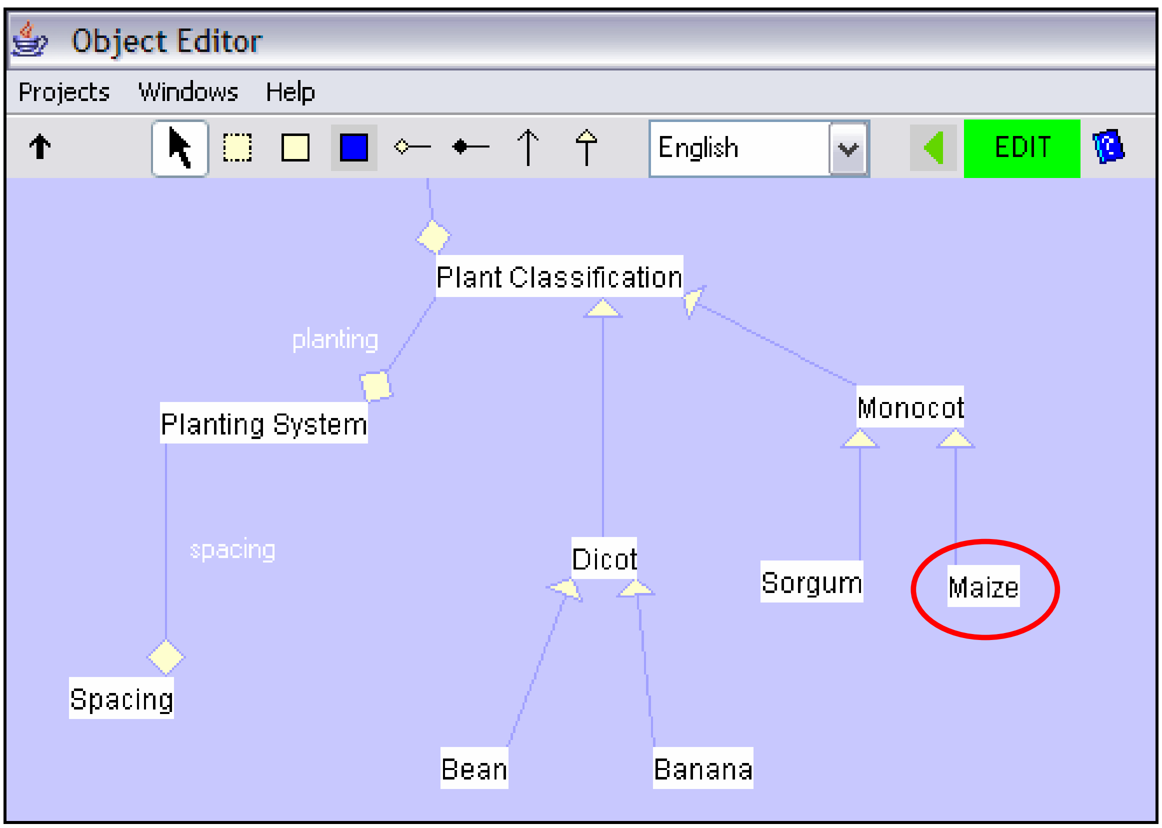


Figure 4-10. Maize instance within the plant topic in the irrigation ontology

The second step is to enter a short definition (gloss) for the instance; this gloss helps to identify the instance. A context is also given to the instance, in the case of maize the context is related to the plant module (Figure 4-11). It is important to observe that the name of the instance and the gloss are given in English and Spanish.

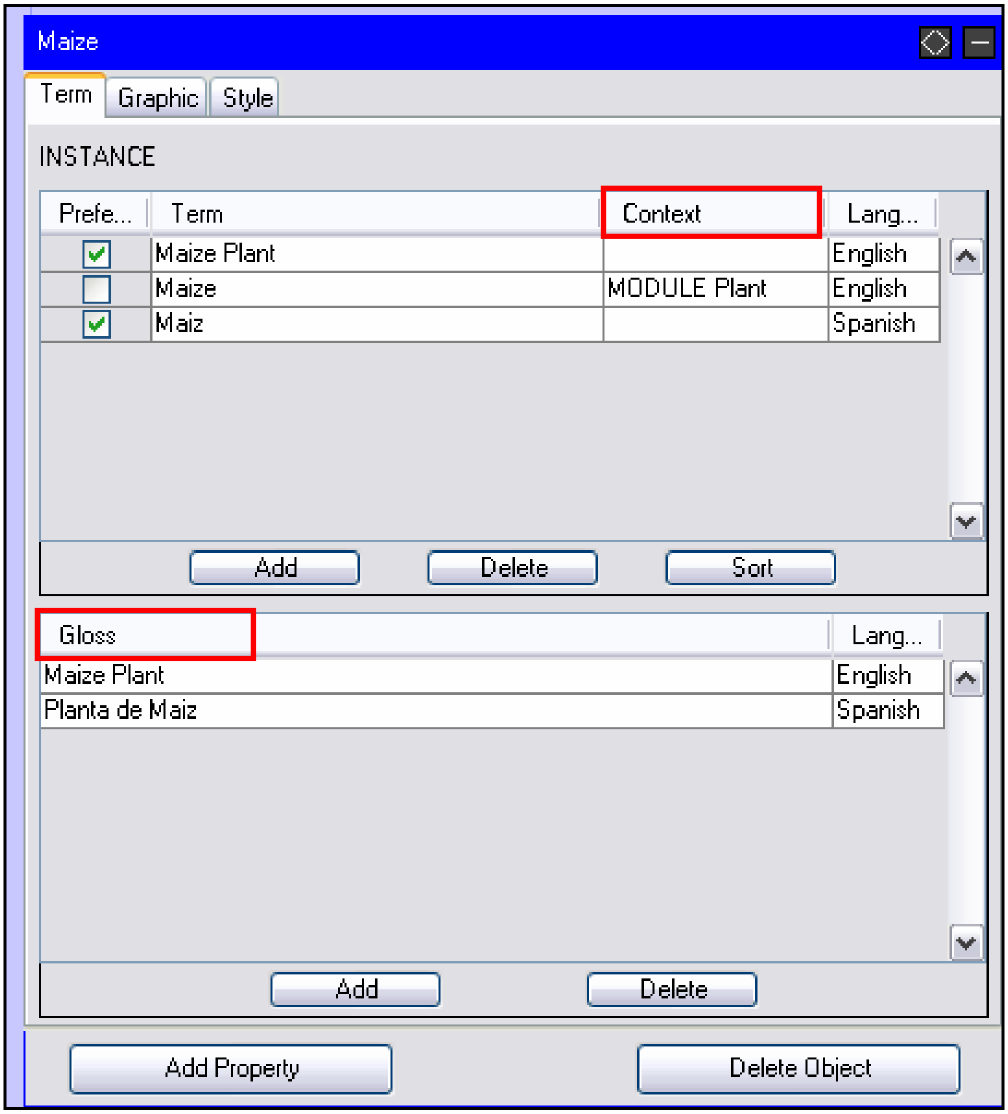


Figure 4-11. Context and gloss for the maize instance

The third step was to create the vector graphic using the GraphicsEditor incorporated in ObjectEditor. The maize plant graphic was constructed from multiple polygons. Next, the polygons are selected and associated in a group. Using the group function properties, names were given to each group (i.e., Maize plant, and corn) (Figure 4-12). These properties are the base to have localizable graphics.

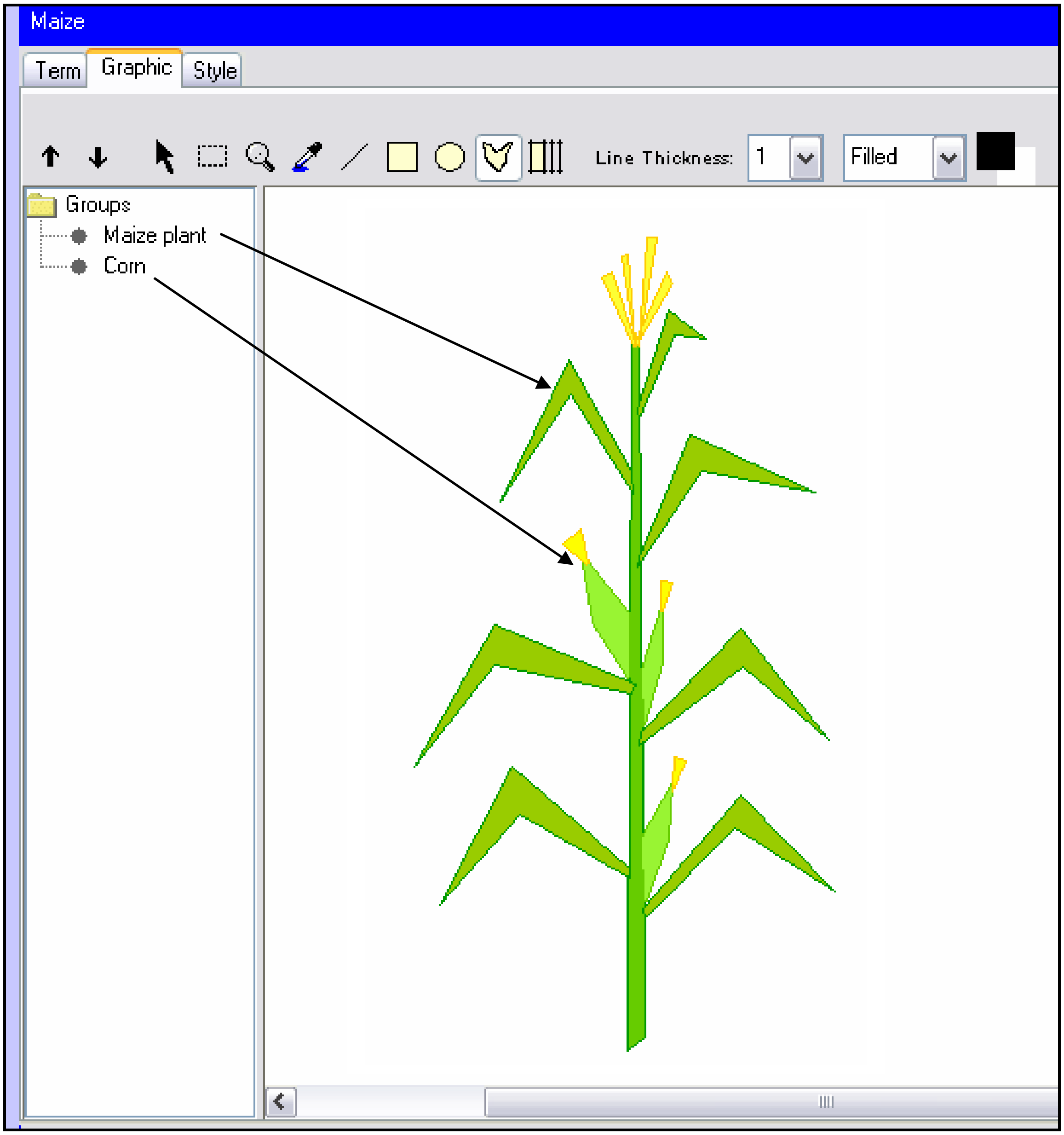


Figure 4-12. Groups that constitute the maize graphic

One of the properties incorporated into the GraphicsEditor creates a path from the of the vector graphic to the object it represent in the irrigation ontology. For example, the skin color in the graphic of a person (Figure 4-13), follows a path to the skin color term associated to the "person" term in the irrigation ontology (Figure 4-14).

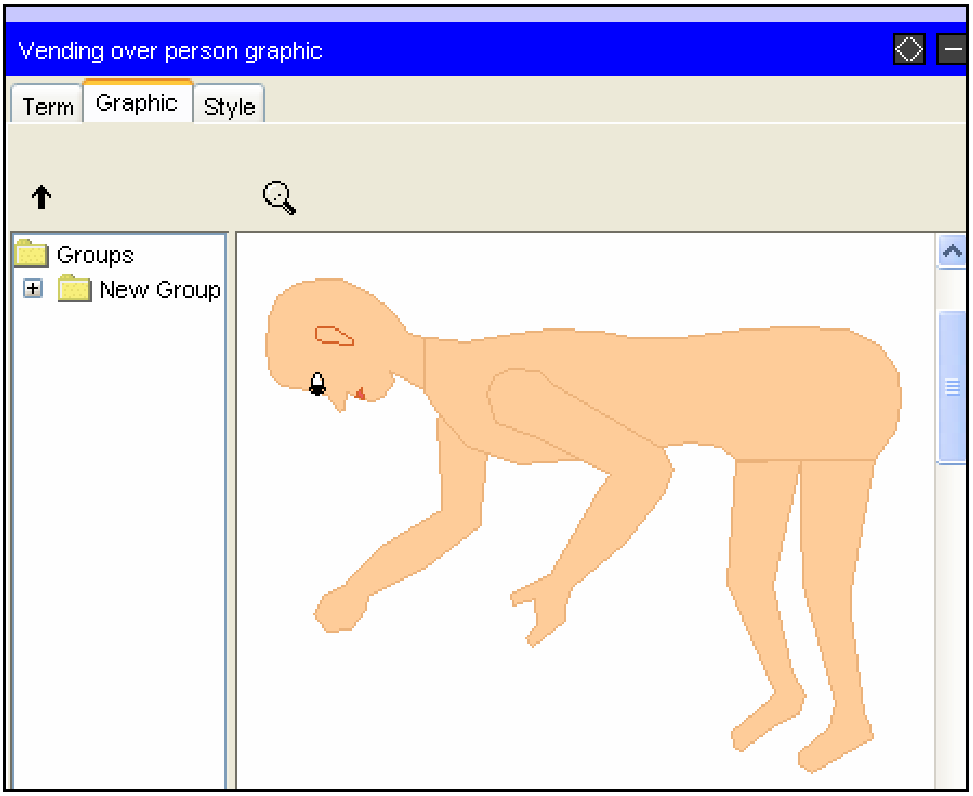


Figure 4-13. Example of a person graphic

This means that the skin color property of the vector graphic is associated with the "skin color" term in the irrigation ontology.

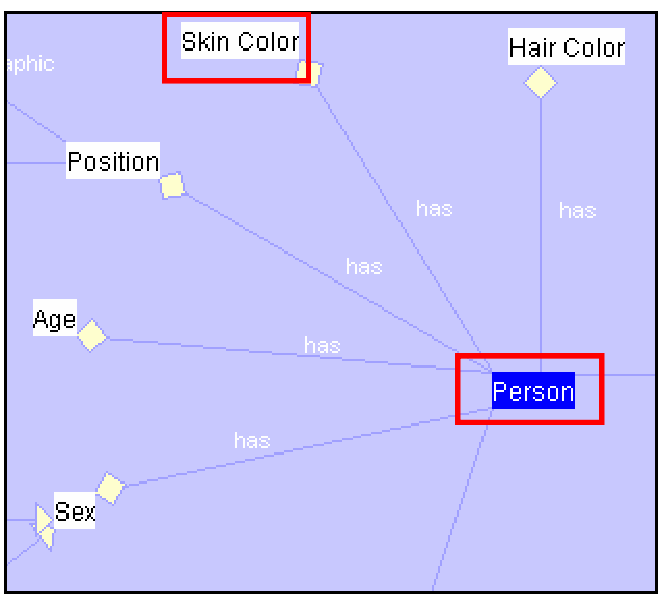


Figure 4-14. Skin color term associated to "person" term

For example, to create a graphic for an African person, the query ‘African person’ could be used. The result of that query would be a person graphic with black skin. The information to change the color of the skin in the graphic comes from the irrigation ontology (Figure 4-15). There is a module in the ontology that specifies the color of the skin for a person from a given geographical region.

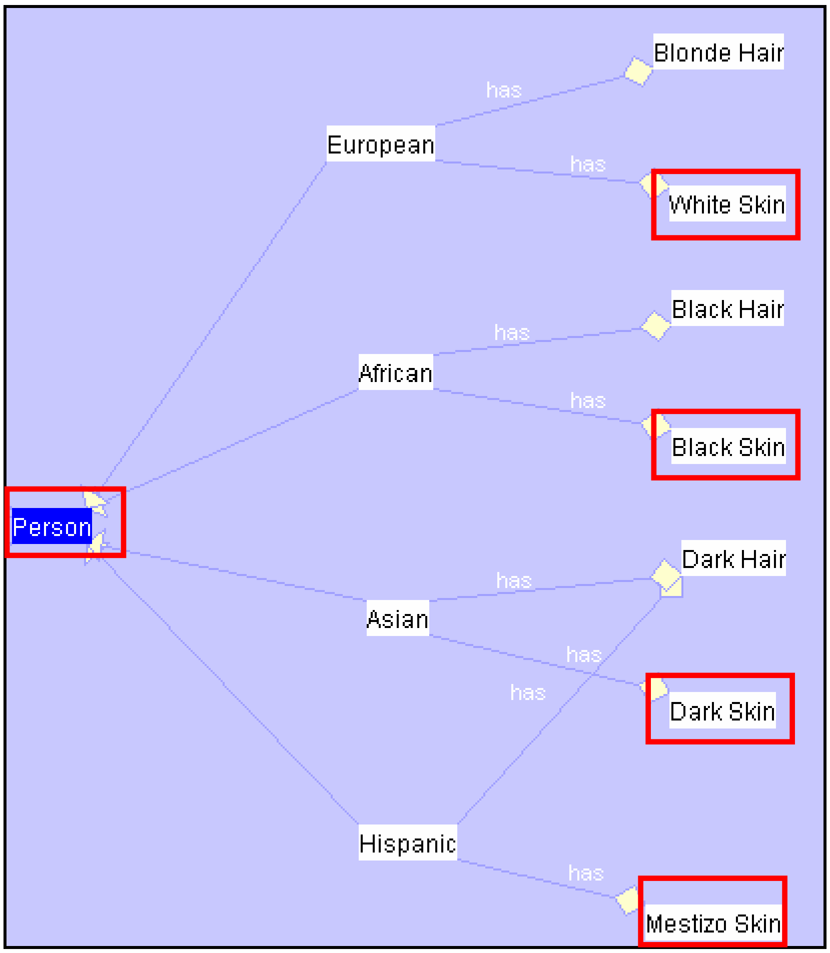


Figure 4-15. Different skin colors depending on the origin of the person

There can be an African person with white skin; however, to facilitate the design of this system the simplification presented in Figure 4-15 was used.

Composing Educational Materials

To facilitate the design of the educational materials a new template module called Irrigation Training Materials was created in ObjectEditor. In this template the topic of the training material was defined, as well as the introduction, materials, activity, and comments (Figure 4-16). In the activity section the steps of the educational activity should be laid out. Each step has a graphical representation as well as a textual description of the action depicted. The steps were organized sequentially using relationships of the sequence type among themselves, meaning that step two has to occur after step one occurs, and so on.

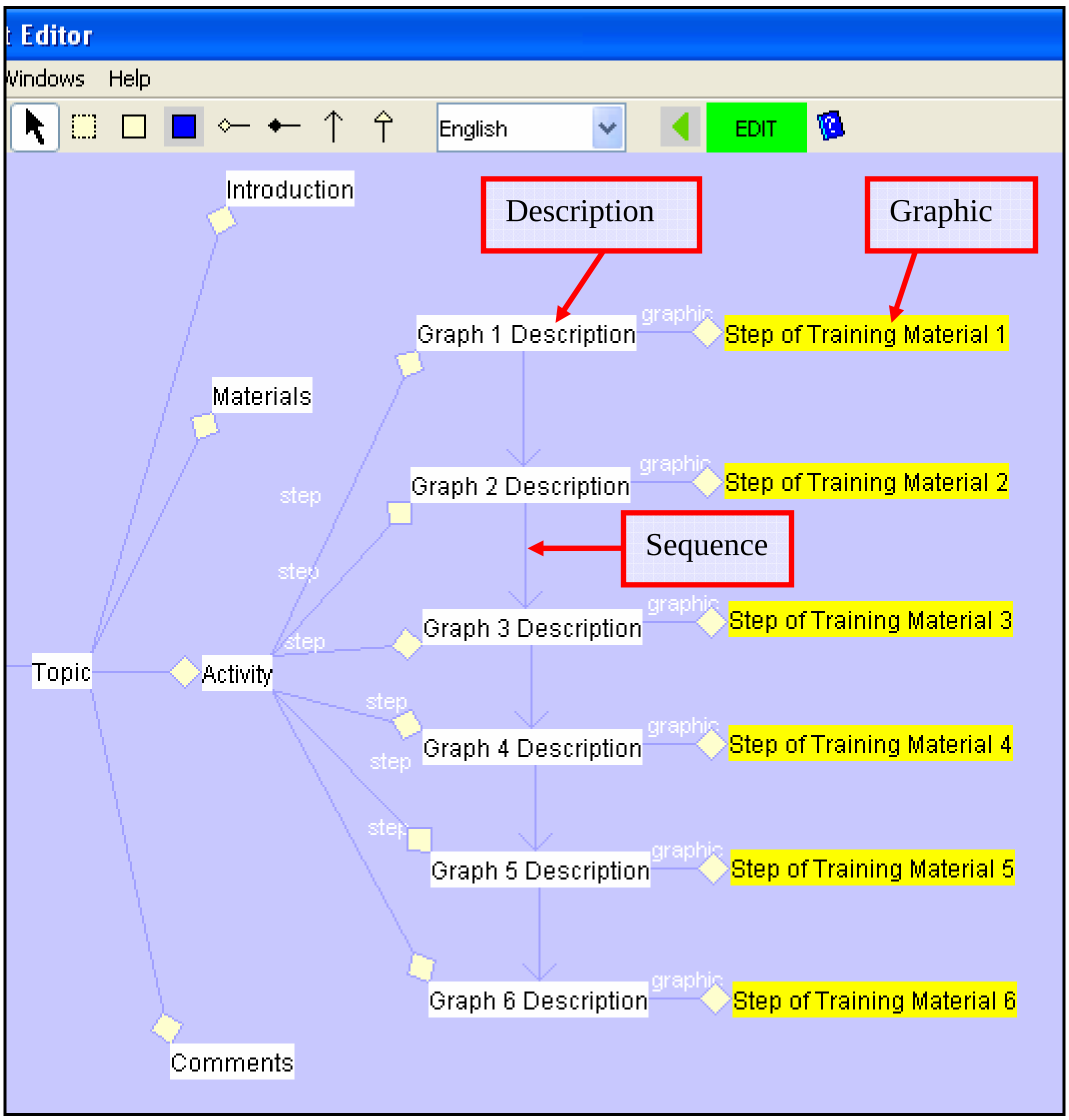


Figure 4-16. Irrigation Training Materials module template

Two options where considered for where to include a description for each graphic. The first option was to add the description in the same instance as the graph. The second one was to add a separate category (class) containing the description. The last option was selected since that one allows the use of the same graphic for different circumstances (educational materials with different topics). Instead of having to change the graphic and its description, only a new and independent description have to be created and associated to the existing graphic (Figure 4-16).

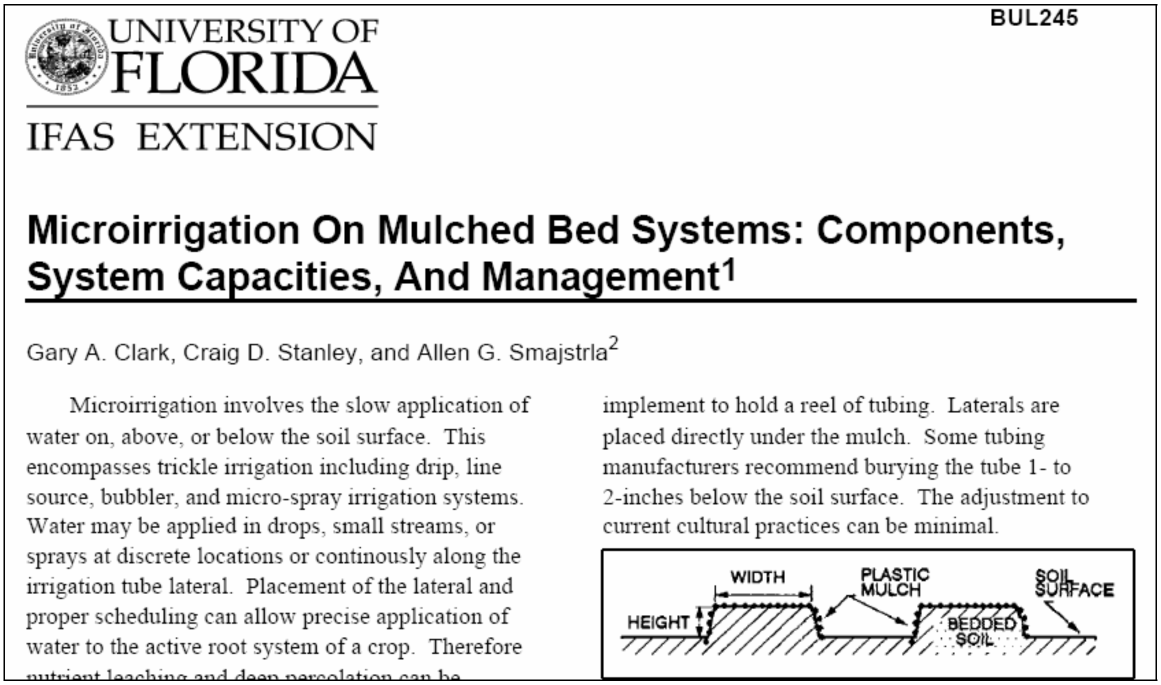
Presentation Generation

The ontology management system used to create the irrigation ontology also stores content (multimedia content in the form of text, images, sound, video, and other content) associated with each ontology concept. Thus it provides content management with the ontology acting to integrate the content. The content also enhances the concept definitions (although not compatible with and essentially ignored by the reasoner, such content provides useful annotations).

Presentations can be automatically generated from this content by specifying a mapping from content objects to the desired presentation. This mapping, which can be implemented using XSL style sheet technology, specifies how content objects are to appear (for example, fonts and colors) and also manages policies on how they can be arranged. Mappings can generate presentations in a variety of different Web page styles, slide show formats (such as PowerPoint) and printed layouts (such as PDF or EPS formats).

A sample for a printed publication on irrigation appears in Figure 4-17, and a sample of a slide-style presentation appears in Figure 4-18. The elements in the printed publication were created using XML FO (Formatting Objects) and a commercial rendering package, RenderX (RenderX, 2004). The process involved 1) generate an XML document from the content for the publication stored in the ontology manager, 2) convert the XML source document to an XML FO based on style specified in an XML style sheet (XSLT), and 3) rendering the XML FO to a printable publication (PDF format) using RenderX.

The approach to the graphics example in Figure 4-8 is to store elements of the graphic using vector graphics. The vectors are stored in the ontology management system as database objects. Larger graphics are composed from smaller elements, much like image libraries in conventional graphics packages. However, the ontology is used to enhance the description of the graphic elements. It not only improves search and retrieval of specific elements, but enables localization at the level of concepts. For example, graphic elements appearing in Figure 4-12 can be changed based on crops grown in a particular location, and people can appear differently (race, gender, and clothing can change) based on local conditions. In other software environments (such as Scalable Vector Graphics) these features must be changed at the level of individual graphic primitives (lines, polygons) but in the ontology management system these primitive elements are given meaning as objects (a plant, a crop, a person with a particular skin color).


UNIVERSITY OF FLORIDA

IFAS EXTENSION

BUL245

Microirrigation On Mulched Bed Systems: Components, System Capacities, And Management[1]

Gary A. Clark, Craig D. Stanley, and Allen G. Smajstrla[2]

Microirrigation involves the slow application of water on, above, or below the soil surface. This encompasses trickle irrigation including drip, line source, bubbler, and micro-spray irrigation systems. Water may be applied in drops, small streams, or sprays at discrete locations or continously along the irrigation tube lateral. Placement of the lateral and proper scheduling can allow precise application of water to the active root system of a crop. Therefore nutrient leaching and deep percolation can be

implement to hold a reel of tubing. Laterals are placed directly under the mulch. Some tubing manufacturers recommend burying the tube 1- to 2-inches below the soil surface. The adjustment to current cultural practices can be minimal.

Figure 4-17. Example of print file generated from the ontology management system.

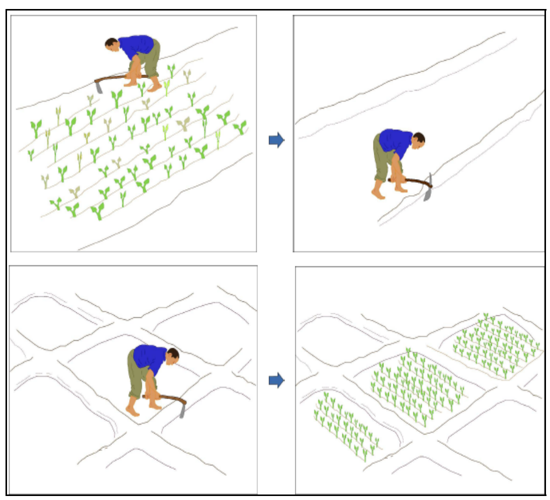


Figure 4-18. Example of educational drawings on irrigation techniques

Conclusion

Any kind of educational material is based on the transmission of information, presenting knowledge in different media like books, audiovisuals, etc. Nevertheless, presenting information to a non-literate audience is more difficult. To “transform” very complex knowledge to a basic representation requires a different approach in the development of educational materials. To develop educational materials easily a better understanding of the learning process for non-literate people is needed.

To develop culturally specific educational materials, information about the culture of the clientele has to be collected. The localized data has to be included during the development of the cultural sensitive educational materials. For this project, information about who (gender, age) performs each irrigation or water management activity is critical for appropriate localization. Also what tools are used, and other complementary factors like clothing, and time when the action is performed, will help to communicate the topic of the educational material to the local conditions.

Scalable vector graphics (SVG) have the qualities needed to produce localized graphics. They can be modified without the need of producing a new drawing, while maintaining all the qualities of a vector graphic. SVG format is supported by GraphicsEditor in order to have a fully functional localization tool for graphics working in conjunction with the object database.

Future work should include the automatic generation of educational materials from the content in the irrigation ontology. The application should be able to generate presentations on-the-fly in multiple formats for any topic in the irrigation domain based on user queries.

CHAPTER 5
EVALUATION OF EDUCATIONAL DRAWINGS IN EL SALVADOR, CENTRAL AMERICA

Introduction

Worldwide, the number of illiterate adults in 2000 was 862 million. According to current trends that number should drop to 824 million by the year 2010 (UNESCO, 2002). The United Nations definition of a literate adult is a person aged 15 or over who can read and write (UNESCO, 2000). In 1995, the literacy rates for El Salvador were 73% for males and 70% for females (UNESCO, 1999). The data highlights the necessity of alternative educational materials, which reduce the effects of illiteracy in the transmission of information. Most of the educational materials in developing countries, with few exceptions, are overwhelmingly print-oriented. In addition, most of the printed materials available are written at a level that makes them inaccessible to individuals with a low education (Hynak-Hankison, 1989; Stemmerman, 1991).

A computer tool to facilitate the production of illustration-based educational materials could make this task much easier and more effective. To accomplish this task, a group at the University of Florida's Department of Agricultural and Biological Engineering researched the possibility of developing a tool and a series of educational materials in the areas of water management and irrigation. The illustration-based materials under development are audience-oriented (from here on referred to as *localized*). For example, if the illustrations are showing a Hispanic person for Latin America, this person can easily be changed to a Black person for African regions to make it more relevant to the local audience. Adjustments can be achieved just by selecting certain attributes from the database, without the necessity of creating a completely new drawing. However, the process of developing a product that meets audience needs, helps accomplish a teaching goal, or solves a problem, is sometimes challenging and may present hidden complexities (Bly, 1989). For the illustration-based materials to be useful, the initial ideas for the drawings were tested with a target population of low-resources small farmers in El Salvador, Central America.

El Salvador is located in Central America; its borders are with Guatemala to the northwest, Honduras to the northeast, and the Pacific Ocean to the south (Figure 5-1). From around 1980, El Salvador was involved in a 12-year civil war, which cost about 75,000 lives. The war was brought to an end in 1992 when the government and leftist rebels signed a treaty that provided for military and political reforms.

Figure 5-1. Map of El Salvador and location of communities visited (CIA, 2004).

El Salvador was selected for this study because of the social and agricultural conditions of the country. The adult literacy estimated rates are considered high – 70% in 2000 (UNESCO, 2002), and 80% in 2003 (CIA, 2004), with a difference of around 10%

between men and women. Illiteracy is more noticeable among elder adults in rural areas, and especially, in the eastern regions of the country (Departments of San Miguel and La Union). Agricultural production in El Salvador is reduced and rudimentary. Most of the fresh fruits and vegetables that El Salvador consumes are imported from Guatemala and Honduras. The production is limited to staple foods like maize and beans.

Rohr-Röuendaal (1997) highlights the necessity of evaluating educational materials; however, she also notices that this is more important when the educational drawings have been developed without direct participation of the final users. Since this work was a first step in the development of a tool to produce on-demand educational materials, the materials were developed away from the clientele; hence, it was important to test them.

The aim of this first field test of the manuals was to identify the level of understanding of the drawings by small farmers in El Salvador; gather their views on the value of the material, and to incorporate any additional material, alterations, or deletions, which would help the farmers to better understand the educational materials. The data collected from this evaluation process would be useful to understand how these specific farmers interpret the educational drawings, and what has to be included to make the manuals practical in a training process. It was important to demonstrate the necessity of testing illustration-based educational materials with a sample of the target audience before they are distributed to a larger population. As the need to develop publications for people with low educational levels continues to grow, so does the importance of special considerations in the content and design process (Ingram, et al., 2004). Audience background (e.g., culture, race) and experience should be considered in all phases of development of the materials. It is also important to understand the differences among people from different cultures, and to learn how people understand the message from educational materials based on drawings. As stated by Rohr-Röuendaal (1997), some people in Africa have never seen a picture or a drawing, and as a result, they are not used to interpreting illustrations as most other people do in everyday life (Clarkson and Johnson, 2001; and AMDM, 1997).

Materials and Methods

The data collection in El Salvador was conducted during July 2004, with the support of PROMIPAC-El Zamorano (Integrated Pest Management Program for Central America) in El Salvador. To collect the data, personal interviews were conducted with 63 small farmers in five different communities: El Peñon, Huertas, Tunas, Singuil, and Pasacarrera. These “caserios” (groups of less than 50 families) were distributed in three departments, Santa Ana in the West, and San Miguel and La Union in the East.

The farmers that participated in the evaluation were part of the farmers’ field schools (FFS) in integrated pest management (IPM) supported by PROMIPAC. These schools meet once a week or once every two weeks for 3 to 5 hours. The topics where mainly focused upon crop production and integrated pest management (IPM). This is important to note since it could be reflected in some of the answers given in the evaluation process.

For this evaluation it was necessary to determine the literacy of small farmers in the visited communities in El Salvador. The sample population selected for this evaluation consisted of people with a low level of education or illiterates. Sixty-three small farmers from five different communities participated in the evaluation. All the farmers are participants of the FFS in natural resources conservation, basic grains production, and IPM.

The questionnaire used in the evaluation contained a set of questions related to any previous training received by the farmer and specifically, to water management practices, and a set of questions on the illustration-based educational materials. In the second section the farmers had to evaluate the clarity of each picture, the message carried by the pictures, and the arrangement of the pictures explaining each activity. For example, the farmers were given five sets of materials (representing: contour planting, earth basins, rain and drainage, retention ditches, and stone lines). There was no oral explanation of the actions represented in each set of drawings to avoid influencing the answers. The questionnaire was developed at the University of Florida by professors with experience in extension work, and water management practices. The questions were evaluated in the field with five farmers and changes were made to accommodate the questionnaire to make it more understandable.

The drawings to be evaluated were developed using scalable vector graphics (SVG) (W3C, 2001b). Scalable vector graphics is a platform for development of two-dimensional graphics. Scalable Vector Graphics are used in many business areas including Web graphics, animation, user interfaces, graphics interchange, print and hardcopy output, mobile applications and high-quality design (W3C, 2004). This graphics language is an open source (royalty free) standard; it is based in the extensible markup language (XML), which was also developed by the World Wide Web Consortium (W3C, 2004b). This allows the interoperability of SVGs, as well as the use of this standard in conjunction with ontologies, and object-oriented databases. Further explanation on this topic is available via Badal et. al., (2004).

The interviews were conducted in groups of five or less people, since this facilitates greater participation and discussion among people. The data was collected individually for each farmer. The structured questionnaire consisted of 15 questions, some general questions about the local conditions relevant to agriculture, and water management practices. However, most of the questions were related to the educational drawings presented to the farmers for evaluation.

The educational drawings to be evaluated were grouped by topics. For example, the drawings related to contour planting were grouped together. The idea was to have a product representing all the steps of a process, similar to an educational manual. Five sets of drawings were presented to the farmers:

- Contour planting or farming
- Earth basins
- Rain and drainage
- Retention ditches
- Stone lines

The drawings were presented in black and white and color versions. This was done in order to compare if there is any significant difference in the interpretation of color versus black and white materials. Also, most of the printed educational material used in extension work is in black and white because it is less expensive than materials printed in color; and the availability of color printing technology is also limited.

Results

After analyzing the literacy data collected from the sample population (63), the values for women are above 80%, and for men are almost 90% (Table 5-1). Literate individuals had from 2 to 6 years of basic schooling, which is considered a low literacy level. Illiterates did not attend school at all. Illiterate people in this study were 30 years or older and 50% of them where 40 years or older (Table 5-2). This shows a recent improvement in basic education in the rural areas.

Table 5-1. Literacy rates of small farmers interviewed in El Salvador.

	Individuals	%	Women	%	Men	%
Illiterate	8	13	3	17	5	11
Literate	55	87	15	83	40	89
Total	63	100	18	100	45	100

Source: Cornejo, 2004.

However, young people still withdraw early from school to help with the economic activities of the family. More than 60% of young adults interviewed in this study had only few years of basic education. The assessment of the literacy level of the sample population could be an important factor in determining how small farmers are able to understand the educational drawings.

Table 5-2. Age groups of small farmers interviewed in El Salvador.

Age Groups	Individuals	Percentage
15-19	1	2
20-29	6	10
30-39	32	51
40-49	11	17
50+	13	21
Total	63	100

Source: Cornejo, 2004.

The objective of this work was to evaluate understanding by the farmers of the educational drawings developed for this project. If effective educational materials are to be developed, then it is important that the information contained in those materials is conveyed to the audience (small farmers in this case). An important thing to consider during the evaluation is if the farmers had been familiar with any type of educational materials.

From Table 5-3, it can be noticed that 94% of the farmers had used text based educational materials. And all of the farmers interviewed have used some kind of educational material, including photographs and video, during different training opportunities. As for all the educational materials tested, 63 small farmers evaluated the drawings.

Table 5-3. Type of educational materials used by farmers in El Salvador.

Educational Material	Have used this type of materials:	
	Individuals	Percentage of total sample
Posters	26	41
Text manuals	59	94
Photographs	7	11
Videos	7	11

Source: Cornejo, 2004.

Contour Planting or Farming

Contour farming (Figure 5-2) consisted of a set of five drawings aimed to represent the use of contour planting. The objective was to show “contour” lines to the farmers evaluating the drawings. Since these are two-dimensional drawings, to show curves and differences in distance can be difficult (to enable proper perspective).

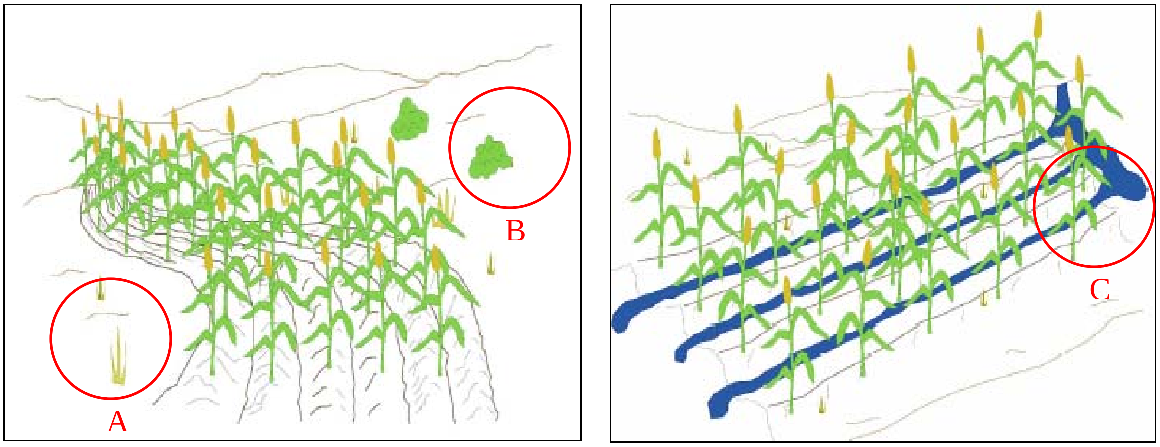


Figure 5-2. Section of drawings representing contour planting

In these drawings, farmers identified the crop as being sorghum (Figure 5-2). The farmers at first were more interested in the crop variety, and trying to identify the other objects resembling plants. Some of the farmers said that “A” was a weed or an aloe plant, and that “B” were eggs laid by some insects, as seen in Figure 5-2. These interpretations confirm the recommendations given by Rohr-Röuendaal (1997), that the drawings should be kept simple, and that all unnecessary details should be avoided. This eliminates wrong interpretations, and it helps people focus on the main aspects of the drawings, the objects that transmit the message that needs to be conveyed.

Slightly more than 56% of the farmers identify the drawings as representing contour planting. Nevertheless, all of the people interviewed recognized them as some type of drainage or land conservation practice. However, it is worth noting that all the farmers had had some training in land conservation practices given by different organizations, according to what the farmers said during the interview process.

Another drawing in this set shows a field without contour planting or any other practice to reduce soil erosion or promote water conservation. In the black and white version, farmers identified the runoff “C” sometimes as water and in some cases as soil or mud. In the color version, the water "C" was easily identified as such. This demonstrates the important that colors may have in the interpretation of illustrations.

Earth Basins

In the second set of drawings, representing earth basin construction, again some of the farmers were more concerned about the type of plant presented to them in the drawing. The origin of this problem could be that no explanation was given about the drawings, since that could influence the answers during evaluation, and the plants are of main interest to the farmer.

From the size of the plants (A) the farmers determined that some vegetables were grown (Figure 5-3) in the field. Then, the answers to the evaluation were related to vegetable production, like land preparation and planting of seedlings.

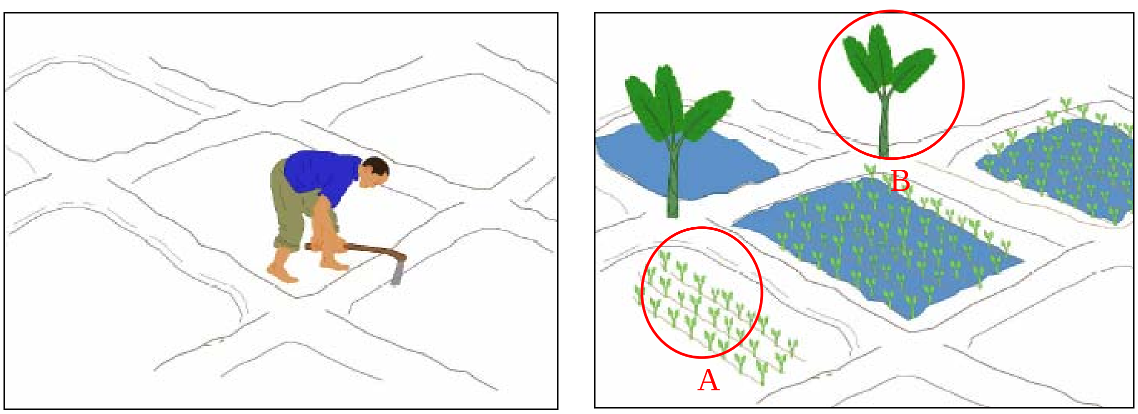


Figure 5-3. Drawings representing earth basins.

Most of the farmers did not have any problem identifying the plantain or banana tree (B). They also identify this practice as the use of intercropping. The object representing the water retained in the basins was easily recognized in the materials presented in colors. When presented in black and white, the farmers interpreted it as soil, mulch, and humid soil. It can be concluded that the color drawing was quite important for proper interpretation as it was in Figure 5-2. None of the farmers interviewed recognized the use of earth basins for water retention. However, it is important to clarify that these educational drawings are not intended to be used by themselves, but as a reinforcement of a comprehensive educational program, with the respective explanations. These materials should be intended to be used as an aid to the farmers to remember the information given during more extensive trainings.

Rain and Drainage

Two of the most difficult things to represent in drawings are abstract ideas and objects with changing scale or relative size. As a result, the drawings in Figure 5-4 were included in the evaluation. With the exception of 5 farmers, the majority recognized the entire sequence of drawings, from cloud formation to the rain, to the damage to the crop. Only one farmer interpreted the damaged crop (A) as being caterpillars, and this was in the black and white copies. The respondents even noticed the water running through the furrows (B).

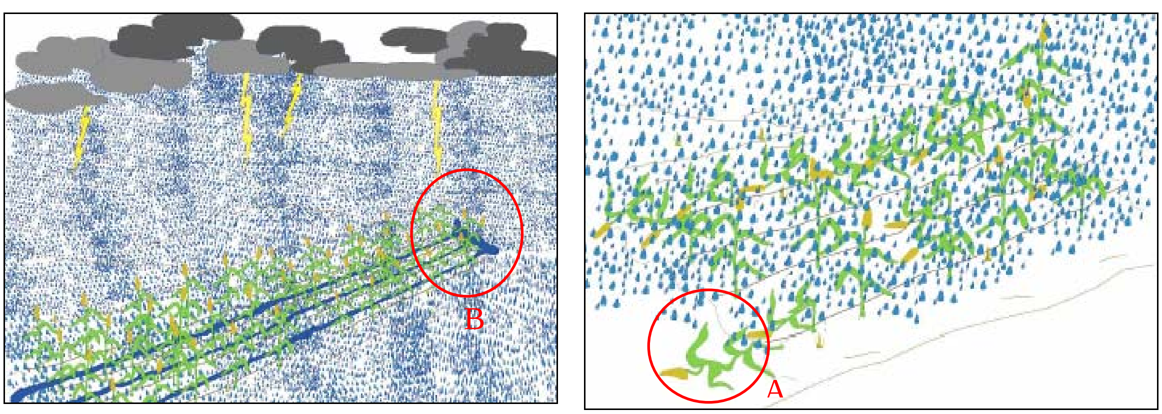


Figure 5-4. Drawing representing rain and drainage.

Retention Ditches

This set of drawings represents the use of ditches to collect rain water (runoff) and retain irrigation water in the dry season (Figure 5-5), as well as to serve as drainage during the rainy season. Some farmers confused the ditch or channel (A) with a road.

This shows the problem in representing three-dimensional objects in a two-dimensional drawing. This could also be a scale problem, and maybe showing a larger field would help in the interpretation of these drawings. A possible solution would be the use of shadows and colors to accentuate the features of objects such as this. With the black and white examples of this manual, farmers had problems recognizing the water (B) flowing in the ditch.

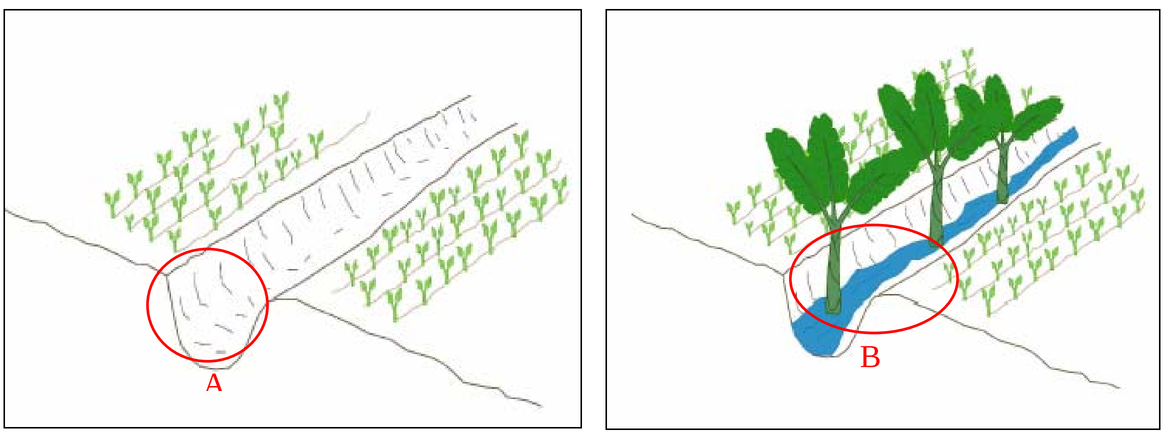


Figure 5-5. Drawing representing a drainage ditch

Stone Terraces (Lines)

There were two problems with how the farmers interpreted this set of drawings (Figure 5-6). First, they thought that the line or barrier of trees (A) was a caterpillar. Second, they identified the stones (B) that try to represent a barrier (terrace) as insects' eggs. Those answers could be related to the training that the participants were recently receiving in integrated pest management. Nevertheless, the farmers that have received training in soil conservation did not have too much problem recognizing the objectives of these drawings.

That means that with some explanation, these drawings easily could serve as materials for recollection of more comprehensive training as it was intended. This point is important, because it helps to highlight that no educational tool is intended to be used alone. These illustration-based materials are designed to complement the training given by an extension agent, within a well structured educational program. They are intended as a tool that will help the farmers remember the concepts learned during the training sessions.

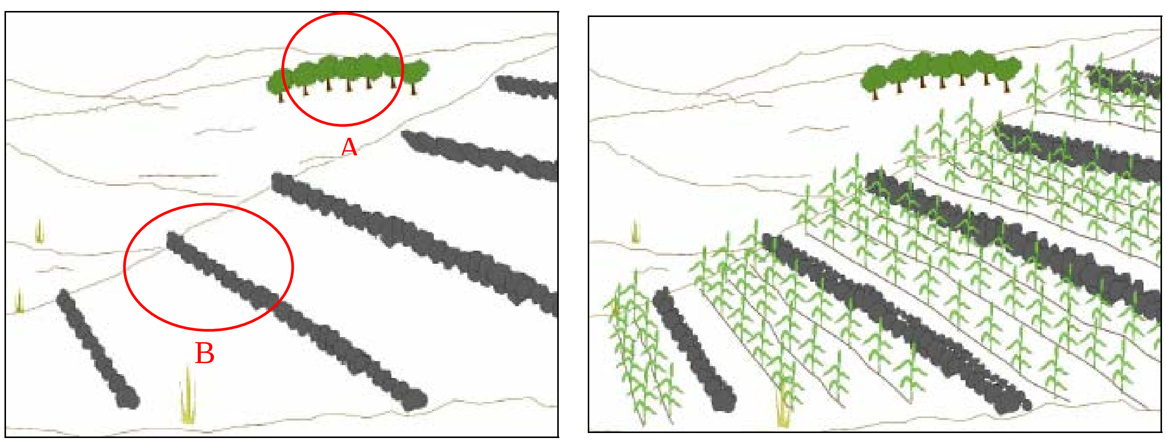


Figure 5-6. Drawing showing stone terraces or lines

Connectors

All the manuals use connectors to join one drawing to the next. The idea is that those connectors can show the flow of the idea that the drawings are trying to convey to the learner. The figures used to represent connectors in the manuals are presented in Figure 5-7. A dice, an arrow, pointing hand, sticks, and numbers were tested.

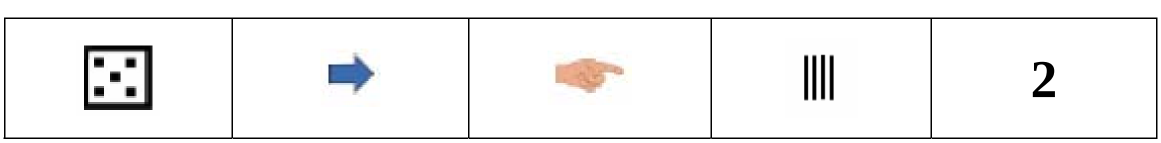


Figure 5-7. Connectors

Different connection symbols were evaluated for use in the tested manuals. The majority of farmers that could not read selected the hands, the dice and lines or sticks. However, there was some confusion with the pointing hands, and arrows. Some farmers thought that arrows and/or hands were being used to point at something specific in the drawings. The people that could read selected the numbers, and lines or sticks as a way to denote order (Table 5-4). It is also important to notice that farmers in El Salvador have had contact with multiple types of educational materials and did not fit the literature model of farmers from some regions of Africa (Rohr-Röuendaal, 1997).

Table 5-4. Drawings' connectors selected by farmers in El Salvador.

Signs	Individuals	%
Hands	17	27
Arrows	12	19
Dice	3	5
Lines	17	27
Numbers	14	22
Total	63	100

Source: Cornejo, 2004.

A main problem in this and other manuals is how to correctly represent actions being performed by people. Since movement is hard to represent in static graphics, the posture of the person in the graphic could help to represent movement. More work is needed in this area, to find a better way to represent movement and actions in the drawings.

Conclusions

Most of the farmers were able to recognize the objects and actions presented in the illustrations. However, some details were difficult to recognize, for example, rows of stones in a barrier were frequently confused with insects' eggs. Also, a line of trees was misinterpreted as a caterpillar. Recent training in Integrated Pest Management conducted with some groups could have contributed to this interpretation. Interestingly, illiterate farmers often asked for some text to be included with the drawings. The reason was that they could ask their children or neighbors to read the text, and that would help them remember the information. It was also observed that the majority of the farmers tend to focus on small details (i.e., shoes of the person, variety of the plants) that are not relevant to the educational message of the materials. It was concluded that caution is needed when including such details since people who produce the materials might not consider important.

All of the farmers that participated in the evaluation process were asked to give their comments in the overall quality and usefulness of the drawings. It is interesting to note that the great majority of farmers who had a problem with understanding a large part or the whole manual were women. Women constituted around 27% of the participants. We can speculate that this could be associated with the limited participation of women in training related to agricultural practices and technologies. Most of the training targeting women in El Salvador is focused towards commercialization of agricultural produce, and other household activities. A common recommendation given by the farmers was to use colors instead of black and white drawings. As stated earlier both color and black and white drawings were evaluated. Farmers stated that colors would facilitate the recognition of some features as crops, water versus soil, and insects. However, when the educational materials are to be developed in field offices by training agents, the availability of color printers or copiers is limited, and in most cases, when available, the costs are still prohibitive for most training programs in developing countries. The manuals were printed in 22.5 cm x 28 cm (8.5 in x 11 in) paper with four frames per page. Some farmers with vision problems recommended the use of larger drawings. Again, this shows the necessity of considering all the factors that could improve the perception of the educational message.

The most relevant comment is that all the farmers prefer to have text explaining the actions shown in the drawings. Even the people with lower levels of formal education and illiterates supported this – as these farmers stated that their children or a neighbor could read to them. Also the farmers confirmed the notion that the manuals need to be accompanied by an explanation of the processes being represented. Manuals presented without any explanation often would lead to misinterpretation and confusion. This can carry serious consequences depending on the topic of the educational materials (i.e., agrichemicals and toxic material applications).

With the number of illiterates still high worldwide, and most of them being farmers in developing countries (UNESCO, 2002), there is a necessity of alternatives to text-based educational materials. The use of illustration-based materials is not new. However, they are usually not relevant to the specific characteristics of the target audience, or have not been tested to assess how well they are understood.

This project has confirmed the necessity of evaluating educational materials to be used in the training of farmers with low levels of formal education. Good illustration-based materials have to be understood by the audience to be considered useful, and the only way of assuring this is through the use of field evaluation. Too often extension program specialists ignore this fact and produce educational materials that are not well suited for the specific conditions of the farmers.

Some general points to follow when developing illustrations for educational materials are defined.

- Educational materials are supplemental to the learning process facilitated by an extension agent or other educator.
- When possible the audience should be included in the development of the educational materials and the illustrations to be included. This can increase the inclusion of local features the improve understanding of the information.
- Some people are not used to recognizing actions conveyed using drawings, especially in remote rural areas.
- Is important to understand how the audience interprets the message from the illustrations.
- The use of conventional symbols like arrows, crosses, has to be analyzed in a local context.
- Distinction of cultural differences (races, clothes, tools) are important hence the necessity of localization.
- Even if the audience has a low level of education or is illiterate, the inclusion of one sentence defining each action is recommended.
- The number of illustrations needed to express a simple task can be large. There has to be a compromise between the number of illustrations and the clarity of the message.
- The shape, size, color of the materials can be important to attract the attention of the audience.

The evaluation of educational materials performed in El Salvador, could improve the quality of the materials developed using a computer tool for production of personalized illustration-based extension manuals. It could also allow the development of evaluation guidelines for educational materials produced using this new tool. This could enable the inclusion of variables like language, culture, gender, and other factors that affect how the farmers interpret and accept the information provided using educational materials.

The types of educational materials presented here are not only important for farmers in developing countries but also in developed nations. Miller (2001) states that in the order of 40 million Americans age 16 years and older have low literacy skills (U.S. Congress, Office of Technology Assessment, 1993). Moreover, the importance of the evaluation of educational materials and the development of new tools to produce them is not limited to agriculture; they could be applied to the education of children, and adults with disabilities.

CHAPTER 6
SUMMARY AND CONCLUSIONS

Summary and Conclusions

The irrigation ontology acts as a database for organizing and storing content. One of the uses for this ontology is organizing irrigation information consisting of documents, images, and other media. The irrigation ontology was used for physical storage, manipulation of content, terms and relationships. The irrigation ontology provides a conceptual map to which media can be attached and which people can navigate to find information. Other advantages of incorporating an ontology include better ways of representing concepts, ability to support natural language-based references to objects, graphic browsing based on data visualization of ontologies, and ontology assisted search.

The irrigation ontology should allow for easier collaboration among specialists by using a common set of terms in order to exchange information or to produce collaborative publications, with the capability of reusing existing information. It should also allow the management of a larger amount of data while providing improved searching capabilities compared to the actual browsers. In this dissertation a methodology to create an irrigation ontology and to develop educational materials based on vector graphics coupled to this ontology were presented. The ontology modeling methodology was presented in two chapters; specification, conceptualization, and evaluation were explained in Chapter 2; while formalization and implementation are presented in Chapter 3. The irrigation domain ontology was used as an example to demonstrate all the modeling process. Chapter 4 illustrated the incorporation of vector graphics into the irrigation ontology to allow the development of illustration-based educational materials. In Chapter 5, the field evaluation of the educational materials conducted in El Salvador (Central America) was presented. Finally, a summary of the dissertation and conclusions is presented here in Chapter 6.

The main objective of this dissertation was to develop an ontology for the irrigation and water management domain. Secondary objectives of this study were:

- To demonstrate the necessity of a tool to create didactic manuals especially for people with low literacy/education levels, or little knowledge of the topics.
- To adapt a process to develop ontologies in the agricultural domain.
- To present the information on more than one language (i.e., English, Spanish) and other characteristics that will allow localization of the materials to be developed.
- To find a technology capable of creating didactic manuals "on-the-fly" for extension education, and to print those materials "on-demand."
- To evaluate the illustration-based educational materials in the field.

During this project it was learned that ontologies can be used to solve problems related to the terminology used within a given domain. Ontologies can be used to organize metadata and to order concepts in a given domain, while allowing browsing, search, tagging and classification of documents. It was shown that the irrigation ontology can be the basis for a system aimed at the development of localized educational materials for people with low levels of formal education.

In Chapter 1, a process was adapted to model the irrigation ontology. This methodology process shown to be an efficient method to develop a domain ontology manually. Collaboration among various specialists in irrigation and knowledge modeling was necessary, and should be encourage, for the development of a common ontology. Specification and conceptualization are important to the entire ontology modeling process. During these two steps the foundation for the ontology was laid. The domain, objectives, and limitations of the irrigation ontology were defined. This helped to guide the rest of the modeling process presented in Chapter 3.

Formalization and implementation were presented in Chapter 3. This was the actual creation of the ontology, where all the terms and relationships were implemented using ObjectEditor. The main issues presented during these steps are the correct definition of terms, as to maintain the semantic sense of the irrigation ontology. The other main issue is to include all the terms covered by the ontology’s domain.

At this time the Irrigation Ontology consists of more than 270 terms, and around 300 relationships among those terms (Appendix A). A comparison was conducted between the irrigation ontology, and the following thesauri AGROVOC, NALT and IWMI descriptors. The terms in the irrigation ontology were matched to the same terms (or synonyms) from each of the other datasets. IWMI contained 15.8%, AGROVOC 22.1%, and NALT 27.68% of the terms included in the irrigation ontology. Even so, the IWMI descriptors in theory should have more irrigation and water management concepts; this set is the one that has fewer of the terms contained in the irrigation ontology.

In Chapter 4 after the evaluation of some vector graphics software and formats available, scalable vector graphics (SVG) was selected as the format that better conforms to the necessities of this project. The characteristics of SVG are that they can be easily localized. GraphicsEditor was the tool used to create the vector graphics; this tool incorporated into ObjectEditor permitted the localization of vector graphics. The composition of the illustrations used in the educational materials was also done using GraphicsEditor.

A preliminary field evaluation of the illustration-based educational materials was conducted in El Salvador (Chapter 5). The results of the evaluation showed that localization affects the interpretation of the information presented through the illustrations. Also, it became clear that the input from the audience improves the design and understanding of the educational materials. A methodology should be developed to evaluate the efficiency and efficacy of illustration based educational materials. A standard evaluation methodology would reduce the time spent collecting data about the audience and their understanding of the illustration-based educational materials.

In conclusion, this work demonstrated that a domain ontology can be used to store and manage the domain's information. The combination of the capabilities of an ontology with the characteristics of scalable vector graphics permits the creation of localized graphics by using the content stored in the irrigation ontology.

Future Work

The irrigation ontology can be the foundation that underpins the development of other projects that require knowledge modeling, organization, and management capabilities. The ontology can be the basis for a system to manage information resources in the irrigation and water management domain. It could be incorporated or expanded to meet needs for projects that cover different sub-domains of irrigation. By making use of the knowledge contained in this domain-specific terminology and concepts, better information management for the web environment can be supported. A user friendly interface should be developed to expand the use of the irrigation ontology as a foundation for the development of educational materials.

APPENDIX A
TERMS IN THE IRRIGATION ONTOLOGY

Weather: wind, radiation, temperature, precipitation, evapotranspiration, transpiration, evapotranspiration methods, Pan, Penman-Monteith, Blanney-Criddle, crop coefficient, pan coefficient.

Plant: leaf, stem, root, root depth; plant type, planting system, spacing; growth season, growth stage, phenological stages, nutrient requirement, climatic requirement, cold resistance, toxicity resistance, salinity resistance.

Soil: soil chemistry: sodicity, salinity, soil pH, nutrients, electric conductivity; topography: erosion, wind, water, water movement; soil available water: field capacity, permanent wilting point; structure: bulk density, compaction; soil moisture retention: mulch, cover crop, conservation tillage; texture: clay, sand, silt, loam; organic matter, permeability: hydraulic conductivity, infiltration.

Water Sources: water quantity, water quality, reclaim water, municipal sources; surface water, water bodies: lake, river, reservoir; groundwater: unsaturated, saturated; aquifer: confined, unconfined, artesian well, well; root zone: hygroscopic water, capillary water; cost, slope, soil, harvested water: basin wide harvesting, macro-catchment, floodwater; on-farm water harvesting: rooftop, micro-catchment: natural depressions, natural rock dams, retention ditch, planting pit; contour farming: stone lines, terrace, bund, semi-circular, ridge, triangular; earth basin: meskat, negarim.

Drainage: drainage design: collector ditches, tile drainage, lateral ditches, perimeter ditch & dike, beds & water furrows, drain tile clogging; drainage considerations: spacing, alignments, drain depth, drain capacity, outlets, connections; flooding damage, summer/winter time intervals; drain clogging, ochre depositions, sulfur slimes.

System Design: site characteristics, irrigation system layout: spacing, planting system; economic considerations, system uses: crop cooling, freeze protection, irrigation requirement: crop requirement, system requirement: leaching requirement, system efficiency; drainage, system selection, pumping system design: pumping equipment, pumping equipment selection; pumping system efficiency; conveyance system design: ditch, primary channel, secondary channel, pipeline, main line, delivery channel, pipe sizing; water hammer, pressure rating, pressure losses, conveyance system efficiency; distribution system design, distribution system efficiency: gravity irrigation, seepage irrigation, seepage irrigation efficiency, surface irrigation, surface irrigation efficiency; pressurized irrigation, pressurized irrigation efficiency.

Irrigation System Management: irrigation scheduling: timing of irrigation, rainfall measurement, field water budget, soil moisture monitoring; scheduling methods: visual appearance of the plant, water budget, long-term average irrigation requirements, climatic data, direct measurement, soil moisture sensor; irrigation system maintenance: check pump: pressure settings, parts, lubrication; surface irrigation, clean canals; pressurized irrigation: check lines for leaks, clean lines or pipes, clean filters, uniformity test, irrigation system calibration; chemigation: volumetric flow rate measurement, calibration of injection systems, calculating fertilizer injection rates.

Irrigation Equipment and Structures: system control: flow meter, pressure gauge, valve: gate valve, ball valve, vacuum regulator, pressure regulator, automatically controlled valve; filtration equipment: cartridge filter, media filter, disc filter, screen filter, centrifugal filter; conveyance equipment, pipeline, pipe fittings: adapter, coupling, cross, elbow, tee, plug; distribution equipment: sprinklers, guns, emitter: microsprinklers, drippers, bubblers; pumping equipment: dynamic pump, positive displacement pump: reciprocating pump: piston pump, diaphragm pump; rotary pump: flexible impeller pump, vane pump, lobe pump, gear pump, screw pump; chemigation equipment: backflow prevention, chemical flow meters, pressurized mixer tanks; chemical injection equipment: suction side injection, venturi injectors; system controllers: computer controller, soil moisture sensors: TDR, dielectric sensors, neutron probe, resistance blocks, tensiometer.

APPENDIX B
DOCUMENTATION FOR THE IRRIGATION ONTOLOGY

As presented in Chapter 2, documentation is a segment of the ontology modeling process. Documentation it's used to keep a record of the modeling process. The format used for the irrigation ontology records the terms in the left column, and any other data in the right column. The terms are written in a hierarchical order, starting with the most important term. In this case the terms are organized according to the irrigation ontology modules as created in ObjectEditor (Chapter 3). Those modules are: Irrigation Water Sources, Weather, Plant, Soil, Drainage, Irrigation System Design, Irrigation System Management, and Irrigation Equipment and Structures. In the right column multiple information is recorded, from source of information (e.g., literature) related to a given term. Also any comment or explanation about a term can be included; any details that can help guide the ontology modeling, or later on the evaluation and maintenance processes.

Other use of the irrigation ontology documentation is to help other people interested in adapting or reusing the irrigation ontology for their own applications. Having a record of the ontology can help users to share information. It also helps any recovery efforts that may be necessary if part of the ontology is damaged.

Term	Description, Source, Comments
Irrigation	Irrigation
System	Design http://edis.ifas.ufl.edu/BODY_AE064;
Water Source	http://www.ces.uga.edu/pubcd/b894-w.html
Well	Maintenance
Drilled	Well: attributes: Diameter, Depth, Casing http://edis.ifas.ufl.edu/WI002
Driven	
Dug	
Dam	
River (diverted)	
Water Harvesting	
Rooftop	
Micro-catchment = External Catchment	
Natural Depressions	
Retention Ditch	
Contour Farming	
Terrace	
Bund = Ridge	
Semi-circular (instance)	
Triangular (instance)	
Planting Pit = Eyebrow Terraces	
Earth Basin	
Meskat (instance)	
Negarim (instance)	
Macro-catchment	Type of Lining could be an attribute of Canal: concrete; concrete blocks, bricks or stone
Floodwater	masonry; sand cement; plastic; and compacted clay.
Conveyance	Possible benefits of lining a canal include: water conservation; no seepage of water into adjacent land or roads; reduced canal dimensions; and reduced maintenance.
Canal	
Lining	ftp://ftp.fao.org/agl/aglw/fwm/Manual7.pdf
	Metal and Composite could be attributes of pipeline

Pipeline = Pressurized

Friction loss — Reduction of water pressure as water travels over distance and through any kind of restriction

Fittings

Type

Surface Irrigation

Basin

Furrow

Border

Sprinkler Irrigation

Portable Sprinkler

Central Pivot — http://edis.ifas.ufl.edu/WI007

Lateral Moving — http://edis.ifas.ufl.edu/WI010

Fixed Sprinkler Irrigation

Microirrigation

Drip — http://edis.ifas.ufl.edu/WI004

Micro Sprinkler

Chemigation

Soil Moisture Retention

Conservation Tillage

Cover Crop

Mulching

Vegetative Residue

Plastic

Drainage

Removal of excess surface and subsurface water from land, including removal of soluble salts from the soil, to enhance crop growth.

Surface = External

Sub-surface = Internal

Evacuation of excess water from cultivated areas; generally used to describe artificially installed drainage.

Bio-drainage

The flow of water towards deeper layers or lateral outflow from an irrigation scheme; naturally present and sustains irrigation for a limited area and often with a time horizon.

Salinity Management

Leaching	Uses the evapotranspirative power of vegetation, especially trees, to keep groundwater tables deep. http://www.fao.org/ag/agl/iptrid/is_pa_03/is_pa_03_agriculture.pdf
Irrigation Equipment	Maintenance could be an attribute of all the objects that need it.
Pump	Operation and Installation same as case as Maintenance
Centrifugal	Pump attributes: Sitting
End-suction	Installation
In-line	Operation and Maintenance
Double suction	Pump Power can be an attribute that includes Motorized and Manual, as well as the type of
Vertical multistage	displacement. And only the Type of pump has to be an object.
Horizontal multistage	Attributes: Energy Supply: Electric, Diesel, Gas, Solar, Hydraulic Manual
Submersible	
Self-priming	
Axial-flow	Size and Material of Pipe could be an attribute of Pipe.
Regenerative	
Positive Displacement	http://edis.ifas.ufl.edu/WI006
Reciprocating	
Power	
Steam	
Rotary	
Pipe	
Material	
Polyethylene	
Diameter	
Length	http://edis.ifas.ufl.edu/WI011
Thickness	
Fittings = Couplings	
Tees	
Elbows	
	http://edis.ifas.ufl.edu/WI009

- Filter
  - Type
    - Screen — http://edis.ifas.ufl.edu/WI008
    - Disc
    - Cartridge
    - Media
    - Centrifugal

Valves control the flow of water to sprinklers and can be mechanical, hydraulic, electric or a hybrid http://edis.ifas.ufl.edu/WI005

- Valve
  - Pressure Regulator = Reducing
  - Gate
  - Ball
  - Electric
  - Butterfly
  - Air Vacuum Relief = Regulator
  - Backflow Prevention
  - Check
- Pressure Gauge
- Flow Meter = Water Meter — A device used to measure the quantity of water that flows through a pipe
- Sprinkler
  - Risers
  - Head styles
- Dripper

Irrigation Water — Water is essential for plant life processes. A odor-less, tasteless liquid.

- Quality
- Surface
- Ground

What relations they have with irrigation?

Soil — Soil provides the mechanical and nutrient support necessary for plant growth.

- Composition — Soil is a mixture of mineral matter, organic matter, and pores. http://www.oznet.ksu.edu/library/ageng2/L904.PDF
- Structure — Soil structure is the shape and arrangement of soil particles into aggregates.
- Texture — Soil texture is determined by the size of the particles that make up the soil.
  - Particles size — Particles sizes for various textural groups

Available water	Available water for various soil types
Density	Soil bulk density is a measurement of the porosity of the soil.
Porosity	Porosity of a soil is defined as the volume of pores in a soil.
Topography	http://www.uwsp.edu/geo/faculty/ritter/geog101/modules/soils/soil_development_soil_properties.html
Slope	
Runoff	
Water Content	
Saturation	
Field capacity	
Wilting point	
Oven dried	
Water Logging	
Salinity	
Infiltration	
Environment or Weather	List important climatic events: Flood, Drought, Season
Precipitation	http://soils.usda.gov/sqi/files/Infiltration.pdf
Radiation	
Temperature	Water is transferred from the surface to the atmosphere through evaporation, the process by which water changes from a liquid to a gas
Evapotranspiration	
Plant	http://www.wcc.nrcs.usda.gov/nrcsirrig/irrig-handbooks-part652-chapter4.html
Type	
Resistance	
Drought	Water used by a crop (plant) for growth and cooling purposes
Salinity	Water is extracted from the soil root zone by the root system
Root	
Leaf	= Crop water use
Transpiration	http://edis.ifas.ufl.edu/AE021

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BIOGRAPHICAL SKETCH

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